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FILAMENT COMPOSITE MATERIAL LANDING GEAR PROGRAM, VOLUME II

Bendix Corporation

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FILAMENT COMPOSITE MATERIAL LANDING GEAR PROGRAM

VOLUME II

THE BENDIX CORPORATION
ENERGY CONTROLS DIVISION

TECHNICAL REPORT AFFDL-TR-72-78

AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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13 ABSTRACT

The objective of this program was to explore the utility of boron composite materials in aircraft landing gear construction. The contract work statement required the design, fabrication and test of a boron composite material landing gear assembly interchangeable in both geometry and performance with the main landing gear of the A-37B aircraft.

The use of BORSIC^R-aluminum and boron epoxy materials was explored. Hardware designs were evolved for both materials. The BORSIC^R-aluminum components were fabricated by Hamilton Standard and the boron epoxy components by Hercules, Inc.

One full size landing gear assembly was tested. This assembly was composed or a boron epoxy outer cylinder, inner cylinder and side brace. All attachment fittings were metallic. The assembly was tested for hydraulic pressure containment and static structural strength in the Bendix laboratories.

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FILAMENT COMPOSITE MATERIAL LANDING GEAR PROGRAM

VOLUME II

THE BENDIX CORPORATION
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I-C

FOREWORD

This report presents the work accomplished during the period of 1 April, 1969 to 1 April, 1972 on USAF Contract No. F33615-69-C-1558, Project No. 1369.

The program is sponsored by the Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. Capt. G. Shumaker, FEM, was the Program Manager.

The program prime contractor was The Bendix Corporation, Energy Controls Division and the program subcontractors were Hamilton Standard Division of United Aircraft Corporation, and the Chemical Propulsion Division, Hercules Incorporated. Performance of this contract was directed for Bendix by A. L. Courtney, program management and R. V. Cervelli, technical director. Subcontractor efforts were directed by E. M. Varholak for Hamilton Standard, and by J. Witzel for Hercules Inc.

This report was submitted in July, 1972.

This technical report has been reviewed and is approved.

K. H. Digges
Kennerly H. Digges
Chief, Mechanical Branch
Vehicle Equipment Division
AF Flight Dynamics Laboratory

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DEFINITIONS

e_L, e_T - Lamina strains parallel and transverse to the fiber direction, respectively (in./in.).

e_{LT} - Laminae shear strain parallel and transverse to the fiber direction (in./in.).

e_x, e_y - Laminate strains along the x and y axes of symmetry, respectively (in./in.).

e_{xy} - Laminate shear strain along the axes of symmetry (in./in.).

E_L, E_T - Young's modulus of laminae parallel and transverse to the fiber direction, respectively (lb./in.^{2}).

E_x, E_y - Young's modulus of laminate along axes of symmetry (lb./in.^{2}).

f_L, f_T - Nominal normal stress applied to laminae parallel and transverse to the fiber direction, respectively, (lb./in.^{2}).

f_{LT} - Nominal shear stress applied to laminae parallel and transverse to the fiber direction (lb./in.^{2}).

f_x, f_y - Nominal normal stress applied to laminate along the x and y axes of symmetry, respectively (lb./in.^{2}).

f_{xy} - Nominal shear stress applied to laminate along the axes of symmetry (lb./in.^{2}).

f_{res} - Vectorial sum or resultant of the three laminate applied stress components - f_x, f_y and f_{xy} (lb./in.^{2}).

F_L, F_T - Ultimate allowable normal strengths of a laminae parallel and transverse to the fiber direction, respectively (lb./in.^{2}).

F_{LT} - Ultimate allowable shear strength of a laminae parallel and transverse to the fiber direction (lb./in.^{2}).

F_x, F_y — Ultimate allowable normal strengths of a laminate along the x and y axes of symmetry, respectively (lb./in.^{2}).

F_{xy} — Ultimate allowable shear strength of a laminate along the x and y axes of symmetry, respectively (lb./in.^{2}).

F_{res} — Vectorial sum or resultant of the three laminate allowable strengths - F_x, F_y and F_{xy} (lb./in.^{2}).

V/O — Filament content (% by volume).

μ_{LT}, μ_{TL} — Poisson's ratio for a laminae relating contracting in the T direction due to extension in the L direction and vice versa, respectively.

μ_{xy} μ_{yx} — Poisson's ratio for a laminate relating contraction in the y direction due to extension in the x direction and vice versa, respectively.

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SECTION VIII

FABRICATION AND PROCESSING

8.0 INTRODUCTION

This section describes the processing procedures associated with the design trial specimens and prototype components designed during this program. The information is arranged as indicated by the following paragraph listing.

- 8.1 BORSIC-Aluminum
  - 8.1.1 Fiber and Tape Sources
  - 8.1.2 Pin Bearing Specimens
  - 8.1.3 Side Brace
  - 8.1.4 Torque Arm
  - 8.1.5 Outer Cylinder and Piston Tubes
  - 8.1.6 Conclusions
- 8.2 Boron-Epoxy
  - 8.2.1 Fiber and Broad Goods Sources
  - 8.2.2 Pin Bearing Specimens
  - 8.2.3 Side Brace
  - 8.2.4 Torque Arms
  - 8.2.5 Outer Cylinder
  - 8.2.6 Piston
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8.1 BORSIC-ALUMINUM COMPOSITE

8.1.1 BORSIC-Aluminum Fiber and Tape Sources

Fiber History

The 0.004 inch diameter fibers for this program were furnished by the Air Force. The fibers were first shipped to the 3-M Company on December 6, 1968 under Air Force Contract No. F33615-69-C-0048. A total of twenty pounds of these fibers were then allocated for use on Phase I of this program. Ten pounds of fibers were shipped to both Hamilton Standard and Hercules/ABL.

The fibers received at Hamilton Standard were examined and it was noted that the spools contained splices which would not withstand the temperatures required in the BORSIC reactor coating process. This problem was resolved internally at Hamilton Standard by trading for filaments which had been spliced with a high temperature material.

Processing BORSIC-Aluminum Tape

The incorporation of fiber and metal matrix material into a monolayer tape is accomplished in basically three operations: (1) mandrel preparation and substrate layup, (2) filament winding of the fiber and (3) plasma spraying of the 6061 aluminum onto the fiber and substrate.

The tape is formed on large winding drums approximately 40 inches in diameter. The mandrels are cut at one face and held in place by tensioning springs. This joint serves as an expansion joint and an area for fiber splicing and tape cutting for removal of the finished tape from the drum. Lengths of 10 feet by 15 inches wide are now obtainable.

The aluminum braze substrate (Alcoa 713) which has a nominal thickness of 0.001 inch, is placed around the drum, care being exercised to prevent the foil from wrinkling. The foil is held in place by tape at the expansion joint of the drum.

The drum is then placed in the lathe-like winder; the fiber is taped at the joint, and the filament winding of the drum is initiated. New splices, if necessary, are done at the joint of the drum so that when the tape is removed all filaments running the length of the tape are continuous.

The drum with the fiber wound on the substrate is then placed on the plasma spray equipment. The drum rotates and indexes in front of the plasma gun at correct speeds to ensure an even deposition of 6061 aluminum. The aluminum powder is injected into the hot argon gas of the plasma arc, melted in the exothermic or recombination zone of the gun, and impacted and quickly solidified on the fiber and substrate. To ensure good adhesion of the matrix and the aluminum substrate, the drums are run at an elevated temperature of between 400 - 600°F, Figure 8-1.

The tapes are permitted to cool and are cut at the joint and removed from the mandrel. The cross section of the tape with the component materials is shown in Figure 8-2.

This material form is considered to be the best form for manufacturing operations. The single ply tape is a mechanically stable structure by virtue of the fixed fiber position uniformly spaced within the tape. The tape form permits ease of handling and may be folded and readily positioned in dies without disturbing the integrity of the fiber spacing or orientation. In addition, single ply tape can be easily cut or punched.

8.1.2 BORSIC-Aluminum Pin Bearing Specimens

This discussion covers the fabrication details associated with the pin bearing specimens described in Appendix C. These specimens were fabricated from monolayer tapes into a BORSCI-aluminum laminate, 21 layers thick. The initial lamina pieces were cut from broad goods into pieces 1.75 inches wide by 7.0 inches long, nine layers at 0° orientation, six layers at -45° orientation and six layers at +45° orientation. Mode of cutting the lamina was by shearing the material on a paper shear. Cuts were made cleanly without any splitting of the tape parallel to the fiber. Cutting of the material and handling were accomplished with white gloves to eliminate contamination of the material through fingerprints.

Figure 8-1. Fabrication of BORSIC-Aluminum Tape

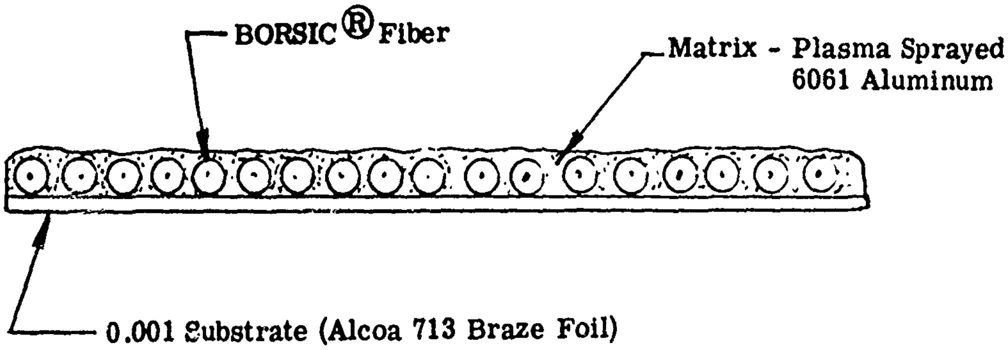


Figure 8-2. BORSIC-Aluminum Tape Cross Section

The individual layers were stacked in a 0°, ±45° array and placed into a vacuum furnace between two platens which contained heating elements. The chamber was drawn to a vacuum of 10^{-5} tor and the pressure of 50 psi was applied. The temperature of the dies was brought to approximately 1050°F and held for 15 to 30 minutes. This holding temperature permits the specimen to stabilize in temperature. The assembly was then increased to 1100 to 1140° and held for 30 to 60 minutes. The assembly was then slowly cooled to room temperature to eliminate any residual stresses.

The pieces were examined and X-rayed prior to having the holes drilled. Consolidation of the laminates was good with the fiber volume calculated to be 53 percent. Void content calculated was on the order of 3.7-4.8 percent. Examination of X-rays revealed no delamination or voids in the laminate with no matrix rich bands in the areas proposed for holes. These laminates were scheduled to have 0.688 inch diameter holes drilled in prior to testing. Drilling was accomplished by utilizing diamond core drills with water cooling. The specimen was then inspected by X-ray prior to testing.

8.1.3 BORSIC-Aluminum Side Brace Fabrication

A description is given of the processing procedure employed in the actual fabrication of the trial specimen and the procedure proposed for the fabrication of the side brace assembly.

8.1.3.1 Side Brace Specimen

This item is described and illustrated in paragraph 5.2.1.1 and Figure 5-10.

The box shaped specimen was constructed entirely of BORSIC-aluminum with the exception of steel bushings located in the pin area. The specimens were composed of six subcomponents which were fabricated separately, machined, and then brazed together in one operation.

Two sets of plates (side plates and flanges) were manufactured per specimen, one set orientated at 0°, the other at ±45°. These were processed between flat platens in a vacuum environment. A pressure of 50 psi was employed at 1100 - 1140°F for 15 minutes after a stabilizing level of 1050°F had been held for 15 minutes.

The lug ends of the specimen consisted of 226 layers of material concentrated in repeatable arrays of $0°_2$, ±45°. Each layer of material was cut to 1.2 x 2.6 inches and prepinched to 0.50 inch diameter to fit over the guide pin in the tooling fixture, Figure 8-3. The sides of the die cavity were painted with a solution of MgO to facilitate release of the part after braze. The layers were placed into the die, the male die member placed on top, Figure 8-4. The die was closed, Figure 8-5 and placed in the ABAR vacuum furnace and brazed at 50 psi, 1100 - 1140°F, for 15 - 30 minutes. At completion of the cooling cycle the laminates were removed, Figure 8-6, and machined to size, Figure 8-7. This particular figure shows the end cut finished. In actual operation, this machining cut was made a finishing operation after the side brace was fabricated.

The composite subcomponents were assembled into the same die in which the lug ends were fabricated with the central filler block removed. All braze joint surfaces were sanded with No. 240 aluminum grit paper and solvent wiped with methyl alcohol. Alcoa

713 foil was employed in the joint; 0.006 inch thick. The plates were bolted into position and the male die inserted into the cavity, (See Figure 8-5). The entire assembly was then subjected to the standard brazing cycle.

Assembly of the first specimen was characterized by several discrepancies. Examination of this specimen revealed:

1. Lack of a braze joint in the cavity area of the specimen in three of the four interfaces.

2. The braze joint of the plates to the lug core was sound with no evidence of voids.

3. The ±45 side plates, due to lack of a joint, were not linear in nature but concaved near the cavity area. The point of maximum curvature was 0.030 to 0.050 inch thick. This is evidenced in Figure 8-8.

4. A slight dent in the edge of the flange which was believed to have been evolved during brazing. (This part, which did not seem to have more of a discrepancy then stated, was in fact a major factor in the failure of this specimen. This is discussed in Paragraph 5.2.1.1.)

This specimen was the first one assembled with no previous processing work performed. Discussion with Bendix concluded that an effort would be made to push the curved side plates in place by the use of a polyurethane foam which would be injected into the cavity through small holes drilled in the ±45° side plates. This foam, BX273-8, used in lightweight propeller blade fabrication, was injected and cured for two hours at 200° F. Partial success was attained but the side rails still remained concaved.

Manufacture of the second plates differed only slightly from the first. A design change narrowing the 0° flanges by 0.040 inch and increasing the width of the ±45° side plates by 0.130 inch was the only change. This change was made to increase the braze area between these four plates. The lug ends were reground from the first specimen and new plates manufactured.

Examination of the second specimen revealed the existence of braze joints between the plates but again concavity of the side plates was in evidence. This time all four were present only to a slight degree.

8.1.3.2 Fabrication of Proposed BORSIC-Aluminum Side Brace Assembly

This item is described and illustrated in Paragraph 5.2.1.1 and Figures 5-20, 5-21 and 5-22.

It was proposed that this assembly be fabricated in two steps. First Hamilton Standard would fabricate and supply the subassemblies shown in Figures 5-21 and 5-22. These items along with other miscellaneous fittings would be assembled by Bendix into the complete side brace assembly shown in Figure 5-20.

1. Hamilton Standard Activity - Fabrication of the BORSIC-aluminum subassemblies would involve five different types of parts: the top and bottom flanges, the end lug cores, the center web, the aluninum angles and the steel bushing.

The flanges would be formed from 13 layers of 0° borsic tape with one layer of 90° borsic tape on each face. A sheet of this orientation would be processed and the flanges cut to size from this panel. Using this same procedure the webs would be fabricated from eight layers of borsic tape disposed in a ±45° layup.

The lug cores would be formed from successive layers of tape forming a $0_2°$, ±45° laminate pattern. These cores would be formed as oversize blocks and the outside contour machined prior to assembly.

All the BORSIC parts and the four aluminum angles would be brazed as an assembly. Aluminum brazing foil approximately 0.001 inch thick would be placed between all surfaces to be brazed together. A brazing die would be utilized to locate the parts and provide the required pressure between mating surfaces.

The pin holes and lightening cavities would be machined after final braze assembly. The bushings would finally be pressed in place to complete the subassembly.

The specific details of processing the BORSIC tape into panels and brazing the assembly are similar to those employed in the fabrication of the side brace specimen and are described in Paragraphs 8.1.1 and 8.1.3.1.

2. Bendix Activity - All the miscellaneous metal fittings shown in Figure 5-20, not included in the subassemblies shown in Figures 5-21 and 5-22, would be procured or manufactured by Bendix. Many of these parts are identical to those included in the conventional side brace assemblies now being fabricated and supplied by Bendix for the A-37B aircraft. The final assembly of the Hamilton-Standard and Bendix supplied parts into the side brace assembly shown in Figure 5-20 would be done by Bendix.

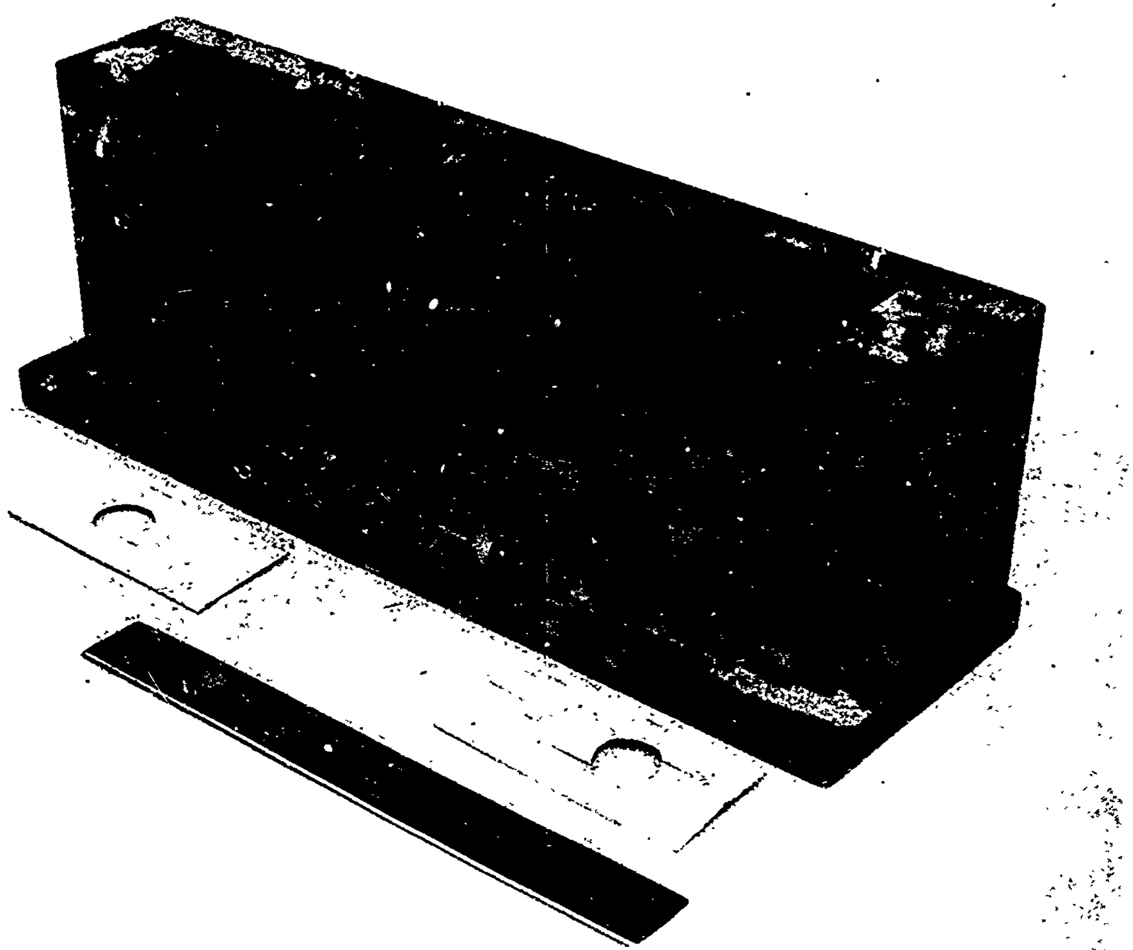


Figure 8-3. Braze Die - Composite Layup, BORSIC-Aluminum Side Brace

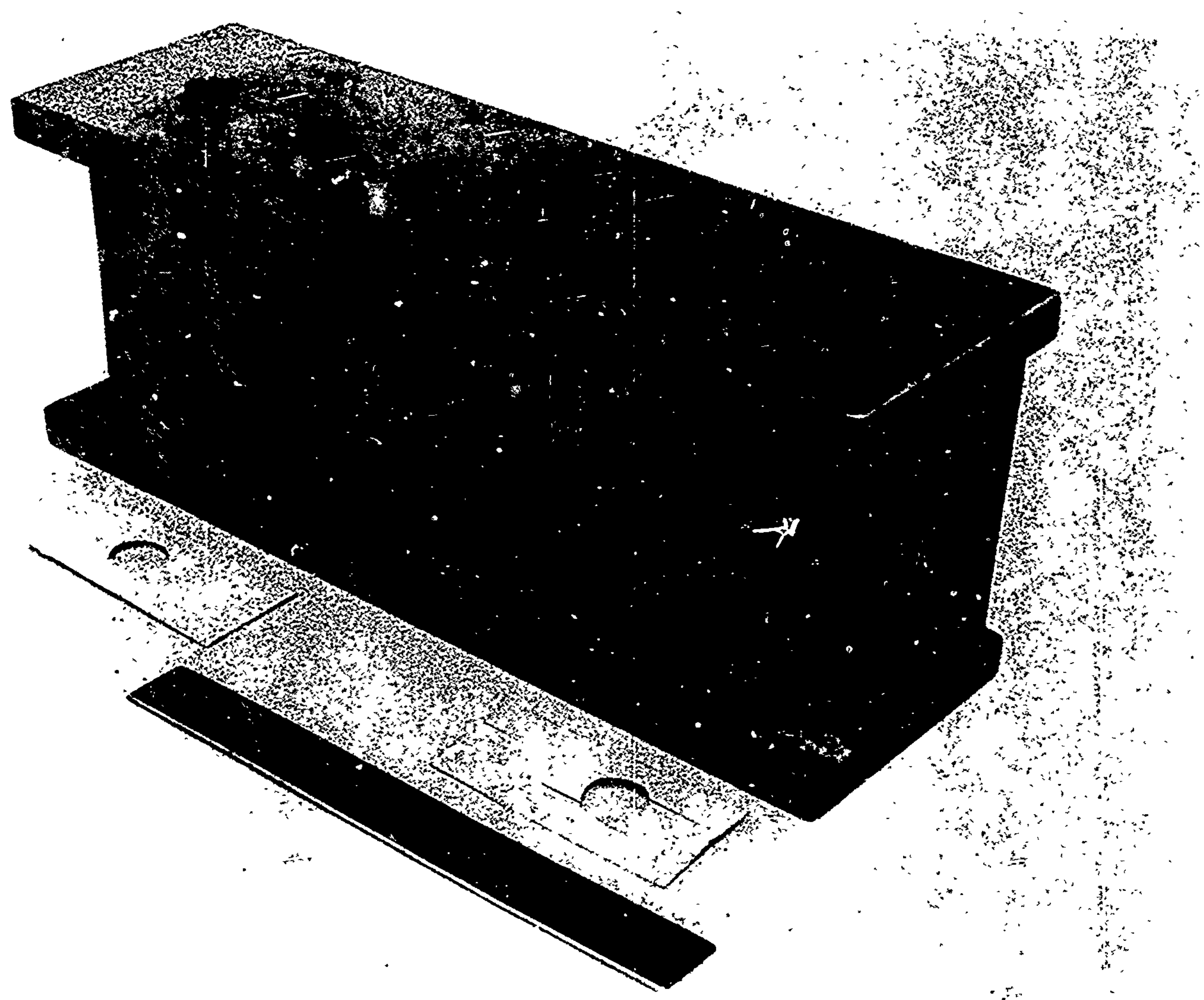


Figure 8-4. Braze Die - Male Half in Place, BORSIC-Aluminum Side Brace

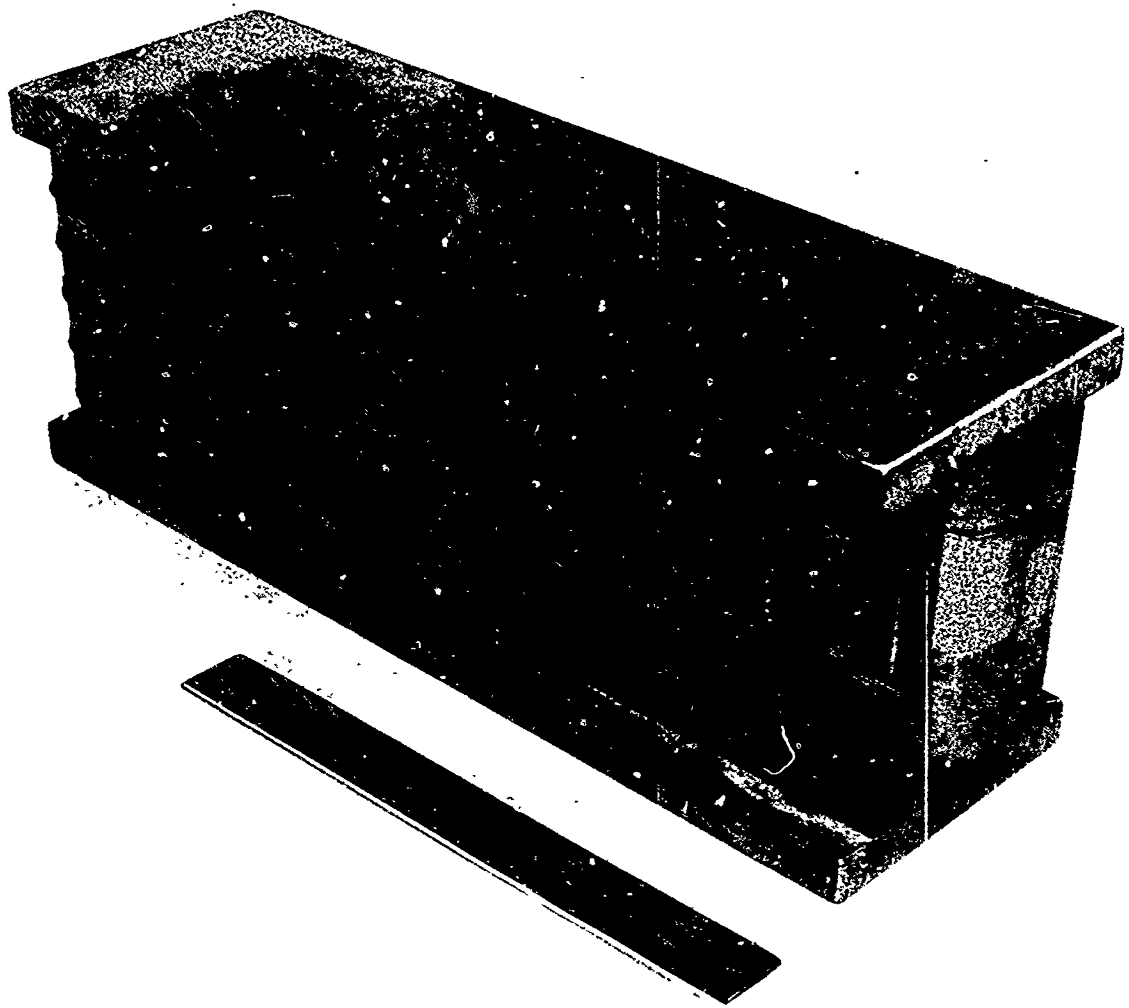


Figure 8-5. Braze Die Assembled, BORSIC-Aluminum Side Brace

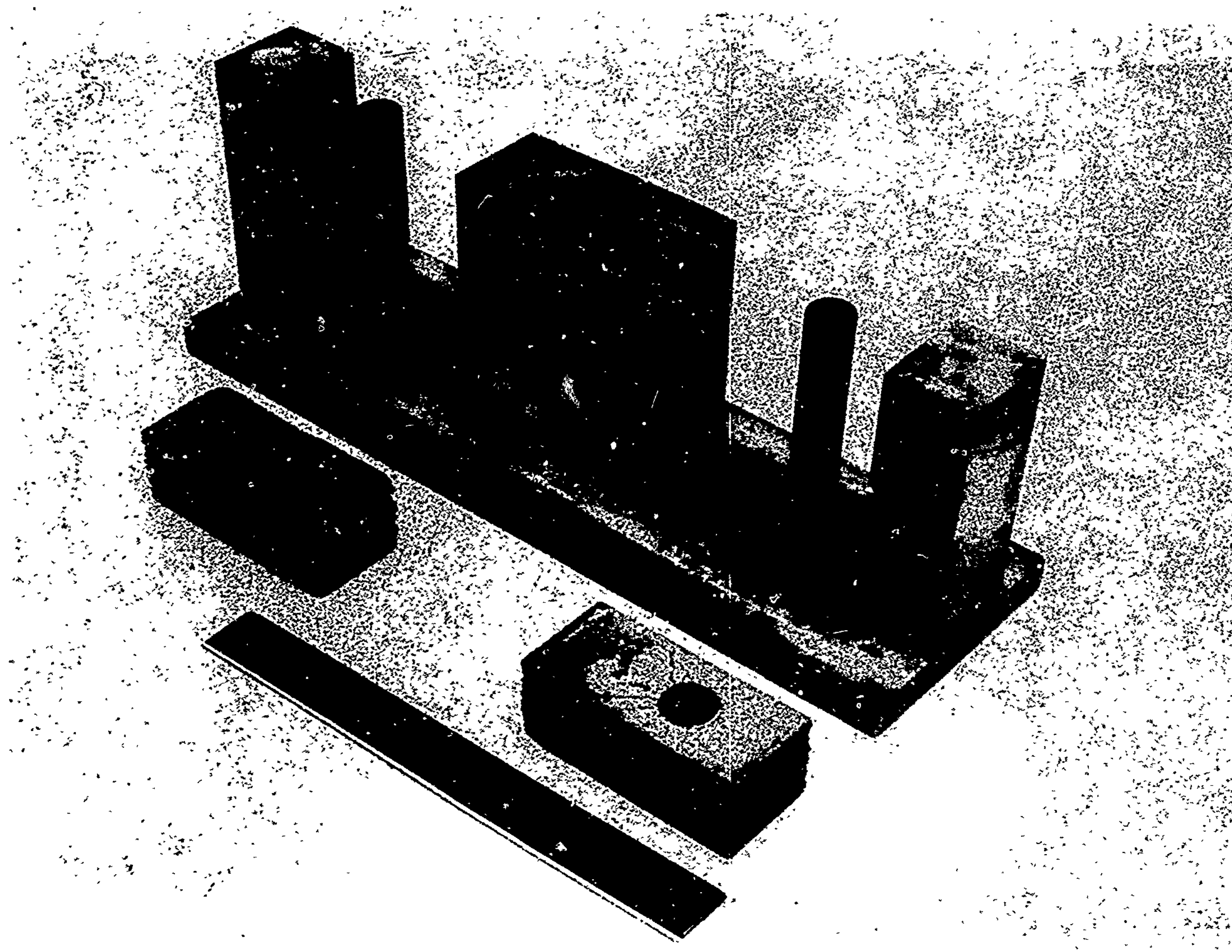


Figure 8-6. Brazed Lug Ends Removed

Figure 8-7. Lug Ends Machined

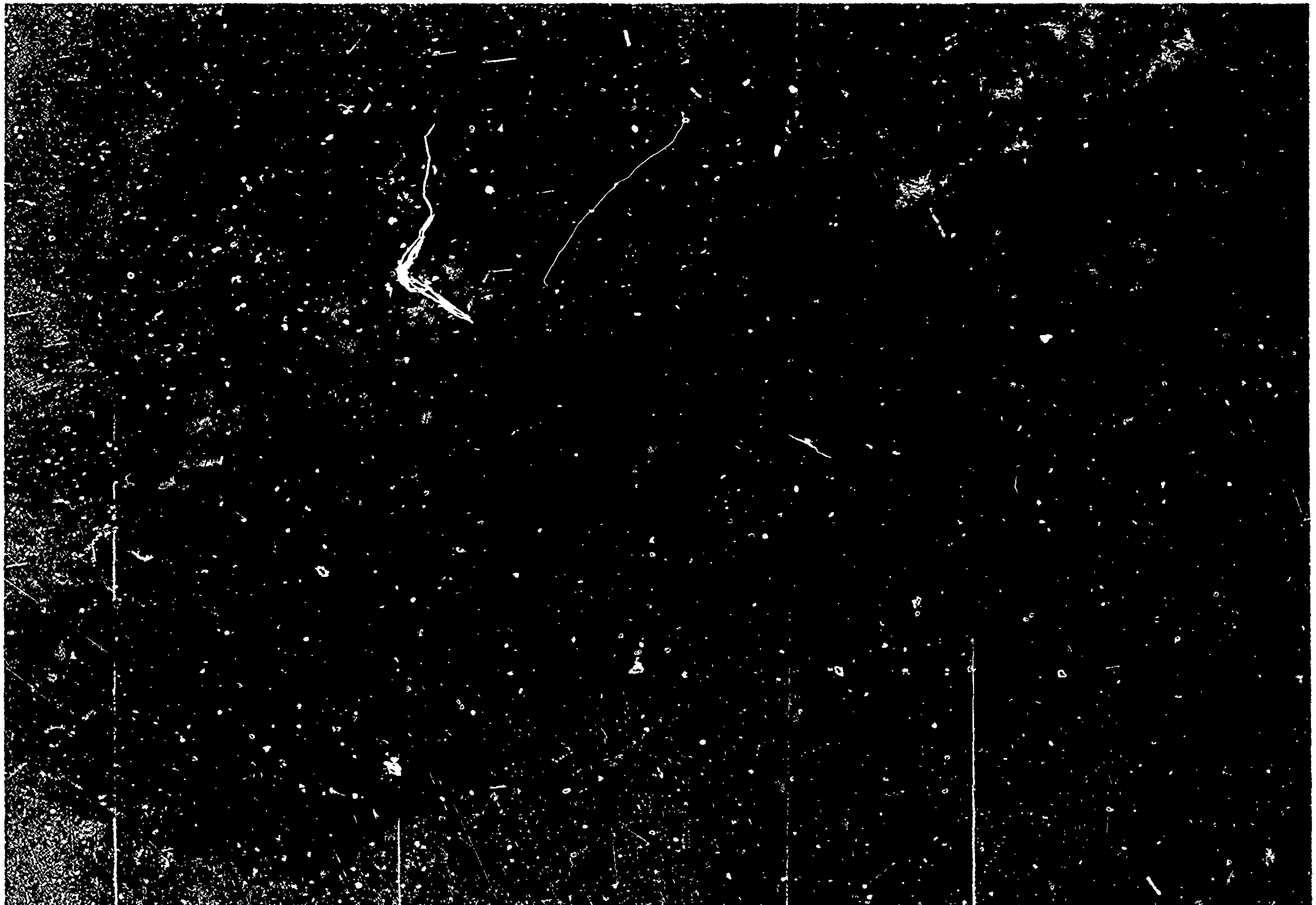


Figure 8-8. BORSIC-Aluminum Side Brace - First Specimen

8.1.4 BORSIC-Aluminum Torque Arm Fabrication

A description is given of the processing procedure employed in the actual fabrication of the trial specimens and the procedure proposed for the fabrication of the prototype torque arm assembly.

8.1.4.1 Torque Arm Specimen

This part is described and illustrated in Paragraph 5.2.1.2 and Figures 5-23 through 5-26.

Prior to manufacture of this tooling, a survey of possible methods for pressure application during braze assembly was conducted. The five methods considered utilized weights, springs (leaf and coil), pressure bag, hydraulic press and differential expansion of metals. In view of the complex shape of the torque arm, a positive means of providing contact and pressure during the braze cycle was needed. Also, pressure in two (2) planes was required at final assembly, which ruled out weights and the hydraulic press. Springs appeared promising but there were questions concerning pressure at brazing temperatures which required answering. Pressure bags were discarded as being too complex for this application. Accordingly, the braze die was designed to fully contain or restrain the assembly and utilize the differential expansion of metals to apply loads during the braze cycle. Materials were selected, AISI 1020 steel for the die proper and AMS 4928 titanium for bolts, that would provide for a fifty percent compaction of the braze foil at braze temperature in the Abar vacuum furnace.

Salt bath brazing was considered but not used due to possible entrapment of the salt in some of the larger braze areas.

The tooling is flexible in that a section of the die serves as a male die for manufacture of the curved rail, Figure 8-9.

Two specimens were assembled; one being built under in-house efforts to act as a process specimen and to serve as a specimen for stress coat evaluation to determine strain gage placement. These specimens, too, were an assembly of six subcomponents each which was formed individually at the standard cycle for 713 Alcoa. The curved rail and lug end were formed in matched dies, the shear plates in a platen press. These composite parts together with the titanium lug end were subjected to machining prior to assembly.

Machining of the titanium end fitting was accomplished with conventional machining equipment and practices. The part was rough machined prior to finish machining to minimize distortion. Boring the bushing holes to size was accomplished after the final braze assembly.

All BORSIC-aluminum details were rough trimmed, 0.030 - 0.060 inch full, on a Doall band saw with a tungsten carbide blade running at a speed of 250 SFR. Wear on the blade was quite rapid and, in addition, loading of the blade with aluminum was a problem. Final machining to size of all details were performed on Brown and Sharpe Model 618 Micromaster surface grinder. Diamond grinding wheels with #60-120 grit were used for finish grinding to dimension. See Figures 8-10 and 8-11 for finished items.

Braze Assembly

The assembly process was accomplished in two steps. The first was to join all subcomponents with the exception of the shear plates. The braze employed for this step was Alcoa 713. The final step was to braze the shear panels with Alcoa 718. This required a temperature of 1090 - 1100° F.

A prefit check of all details was made to assure proper fit of all details prior to braze. The brazing process was as follows:

1. Disassemble braze die and degrease. Remove all dowel pins and screws.

2. Clean all die parts by scouring with Gibson Cleaner and water. Dry in warm air oven at 150° F.

3. Apply one medium coat of magnesium oxide (mixed with water) as a stop-off to all die parts.

4. Degrease titanium end fittings P/N VXC-30974 and scour thorougly with Gibson Cleaner and water. Check for water break. Scour again if needed. Dry in warm air oven at 150° F.

5. Methyl alcohol wipe all BORSIC-aluminum details using clean gauze cloth. Lightly sand all braze surfaces with No. 240 grit aluminum oxide sandpaper. Repeat solvent wipe.

6. Methyl alcohol wipe all braze foil using clean cloth only. Change cloth surface after each wipe.

7. Assemble parts in tooling and braze in vacuum chamber. (All parts assembled with the exception of the shear plates).

8. Cool die. Keep closed until shear plates ready for braze.

9. Repeat steps 6 and 7 with shear panels in place.

10. Cool and inspect.

Inspection

Evaluation of the joint areas visually revealed filled joints with those exceptions as shown in Figure 8-12. For the second sequence, brazing the shear panels in place, Alcoa 718 was employed rather than Alcoa 713 because of the lower temperature requirements (1070 - 1100°F versus 1100° - 1140°F). This eliminated the need to subject the previous subassembly to the remelt condition.

No additional discrepancies were discovered other than lack of filleting in the end of the side rail to titanium in the bearing area. The weight of the finished part was 292 grams, approximately 31 percent lighter than the conventional torque arm employed in the A-37B landing gear.

8.1.4.2 Fabrication of Proposed BORSIC-Aluminum Torque Arm Assembly

The torque arm finally proposed for fabrication in Phase II is illustrated in Figures 5-33 and 6-2.

The torque arm assembly would be fabricated in two steps. First Hamilton Standard would fabricate and supply the subassembly shown in Figure 5-33. This item, along with various metallic fittings to be procured by Bendix, would be assembled by Bendix into the complete assembly shown in Figure 6-2.

1. Hamilton Standard Activity - Fabrication of the BORSIC-aluminum torque arm would involve five different types of parts: The straight and curved rails (flanges), the two shear plates, the inner knee lug core, the two outer lug cores, the titanium end fitting, and the bushings.

The straight rail would be formed from 42 layers of 0° tape and the curved rail from 66 layers of 0° tape. Both rails would be fabricated to a uniform thickness and machined to obtain the tapered sections.

The two shear plates would be fabricated from ten layers of BORSIC-aluminum tape oriented in ±45° directions. A sheet of this orientation would be processed and the plates cut to size from this panel.

Both the inner and outer lug cores would be formed from layers of BORSIC-aluminum tape oriented in a ±45° direction. The cores would be formed as oversized blocks and machined to size prior to assembly.

All the BORSIC-aluminum parts and the titanium end fittings would be brazed as an assembly. Aluminum brazing foil, approximately 0.001 inch thick, would be placed between all the surfaces to be brazed together. A brazing die would be utilized to locate the parts and to provide the required pressure between mating surfaces.

The holes in the knee and root lugs would be machined after the brazing operation and the bushings pressed in place to complete the subassembly.

The specific details of processing BORSIC-aluminum tape into panels and of brazing the assembly together are similar to those described for the fabrication of the trial specimens discussed in Paragraph 8.1.4.1.

2. Bendix Activity - All the miscellaneous metal fitting shown in Figure 6-2, but not included in the subassembly described in Figure 5-33, would be procured or manufactured by Bendix. Some of these parts are identical to those included in the conventional torque arm assembly now being fabricated and supplied by Bendix for the A-37B aircraft. The final assembly of the Hamilton Standard and Bendix supplied parts into the torque arm assembly shown in Figure 6-2 would be performed by Bendix.

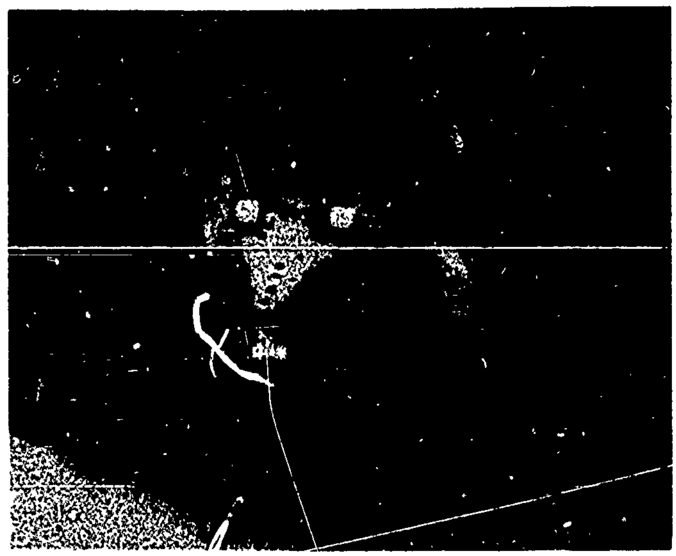


Figure 8-9. Torque Arm Brazing Fixture

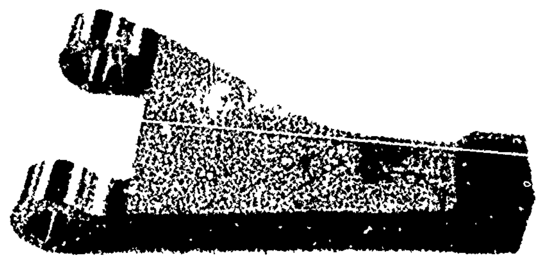


Figure 8-10. Torque Arm Prior to Finish Machining

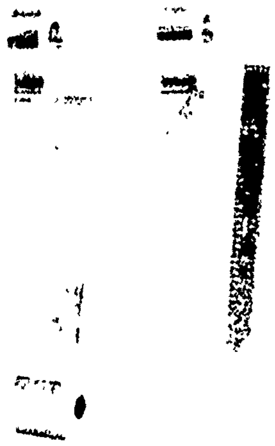


Figure 8-11. Completed Torque Arm Specimen

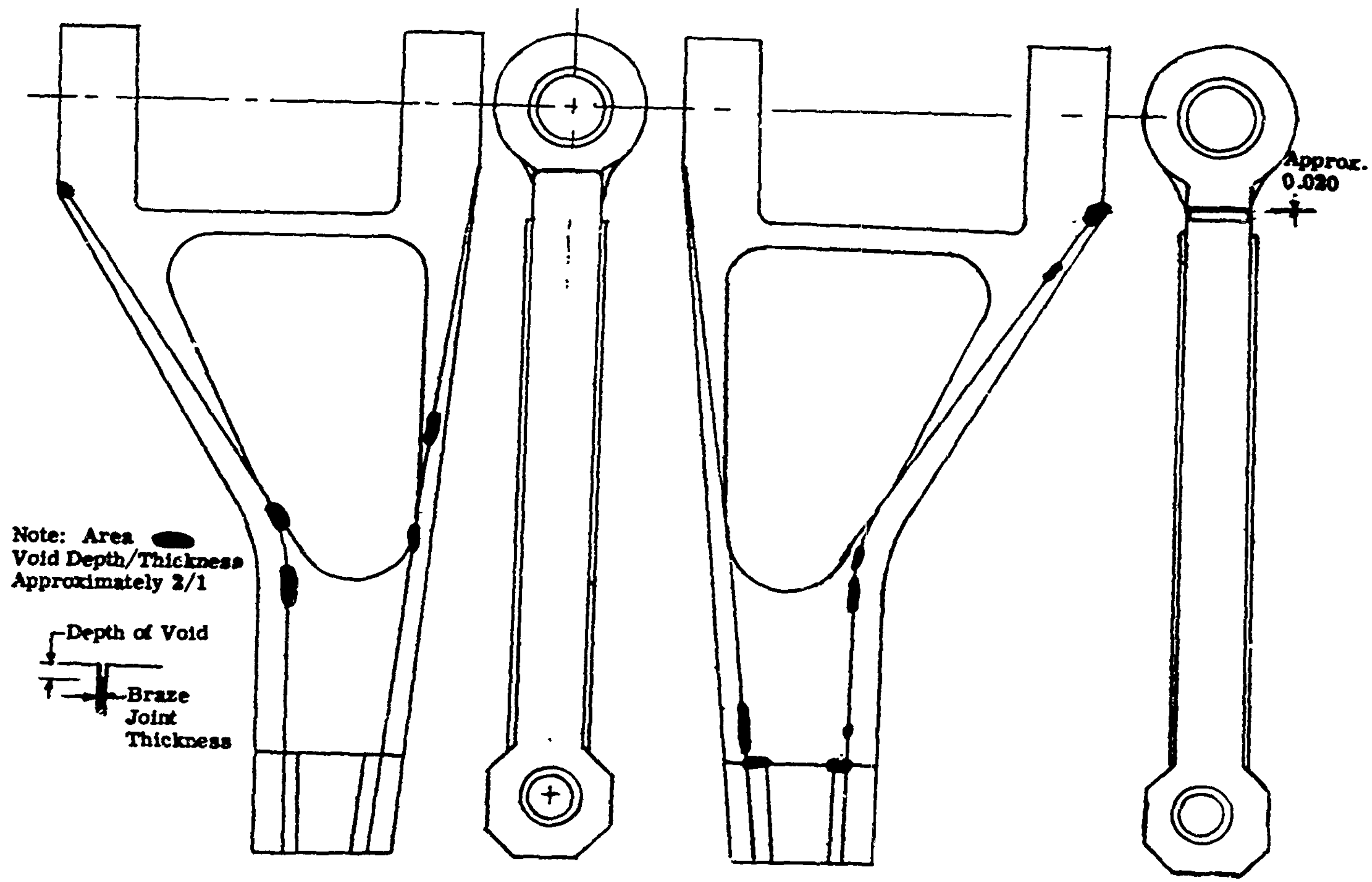


Figure 8-12. Joint Examination

8.1.5 Fabrication of BORSIC-Aluminum Cylinders

The trial fabrication of BORSIC-Aluminum cylinders consisted of a two-part effort. The first effort was aimed at the fabrication of a cylinder specimen with a $(0/\pm45/90)_{13}$ layup suitable for application to outer cylinder construction (Figure 5-34). The second effort dealt with the fabrication of a cylinder specimen with a $(0_{44}/90_8)$ layup intended for use as a piston cylinder.

8.1.5.1 Outer Cylinder Specimen

Emphasis in this section of the program was directed strictly at the determination of processing a cylinder of multiple orientation $(0/\pm45/90)_{13}$. Particular attention was devoted to

1. The feasibility of employing a 1/2-inch wide composite tape to provide the circumferential wraps required, and

2. The degree of compaction attainable in the composite per layer as influenced by the quantity of material (layers) with the fixed fiber arrangement as mentioned above.

Tooling

Tooling for manufacture of the cylinder consisted of a segmented outer mandrel and two sets of segmented, expandable internal mandrels, see Figures 8-14, 8-15 and 8-16. The outer mandrel is segmented into three parts and alumina coated to facilitate removal from the outer surface of the composite structure after brazing. The inner mandrels are slotted and fitted to a tapered loading arbor. Consolidation of the composite is accomplished by radial pressure exerted by the inner mandrels as a result of the wedge action of the preloaded arbor. Material for the outer die was AMS 5616. This material was selected since it exhibits minimal grain growth at the temperature employed in brazing. The arbor of the inner mandrel is of a meehanite type iron while 80-60-03 ductile iron was employed for the sleeves. The different materials exhibit different coefficients of expansion at the braze temperatures, eliminating the risk of the arbor and sleeves binding during the process. The taper on the arbor is 1/4 inch per foot and provides a mechanical advantage of 50 to 1. The diameters of the two inner mandrels are 2.677 and 2.931 with an expansion range of 0.140.

Process Cylinder

The prescribed layup pattern for the cylinder consisted of 52 layers of material in an oriented arrangement as shown in Figure 8-13. This arrangement created a problem in processing since initial conception was based on the premise of employing broad goods in the layup sequence. To accommodate the required sequence would mean that each circumferential ring would have to be cut and butted and the next layer placed over it. This layup would anticipate that the shear loads of the material would have to compensate for the loop strength. Emphasis was placed upon:

1. Evaluation of narrow tape for circumferential wraps, and

2. Determination of degree of compaction attainable as influenced by the number of layers employed as well as group orientation pattern.

The process, in general, was as follows:

1. Material was cut to approximately 13 inches by 10.5 inches for the zero-degree arrangements, 1/2 inch wide for the circumferential wraps and rhombus-shaped for the ±45° arrangements. Care was taken to keep from contaminating the cut pieces and they were stored in plastic containers prior to use.

2. The prescribed layup patterns were layed up on a wooden mandrel to twenty-one layers, (±45, 0°, 90°)50°. Each layer was wiped clean with methyl ethyl ketone and allowed to dry five minutes, prior to layup. Each layer was tack brazed into place to eliminate slippage during the layup. The wooden mandrel is sized by allowing for an average of 8.5 mils per layer in the layup. This value is subtracted from the outside dimension desired.

3. Once the layup was completed, the outer mandrel was placed over the assembly and bolted to provide the finished outer diameter of the composite cylinder.

4. The composite layup was removed from the wooden mandrel and the expandable mandrel inserted and expanded until a tight fit is obtained. Prior to insertion of the inner mandrel, steel foil two inches wide and 0.002 inch thick was coated with a solution of MgO and placed over the segmented mandrel. This serves two purposes - the coated foil acts as a parting agent between the composite and mandrel and, in addition, bridges the segment gaps of the mandrel.

5. The entire assembly was placed in the ABAR Vacuum Furance, Figure 8-17 for the forming and consolidation generation. A cross sectional sketch is shown in Figure 8-16.

   a. Vacuum is applied to a pressure of 10^{-5} tor.

   b. Temperature is increased to 1040° to 1060°F and held for approximately 15 minutes to permit the assembly to stabilize at temperature.

   c. Increase temperature to 1100 - 1140° and hold for 30 to 60 minutes.

   d. Cool to room temperature.

6. Steps 2 through 5, inclusive, were repeated where the cylinder wall was built up further. The number of layers was changed to reflect the degree of additional thickness desired.

Results

Data reflecting the degree of compaction relative to the number of layers processed is tabulated in Table 8-1. The objective, to acquire an average thickness/layer of 0.0048, was not achieved. Reducing the number of layers which were processed facilitated better results, but this too was not sufficient. In Cylinder No. 3, the one which produced the best results, the pressure was increased by a magnitude of four (approximately 350 psi).

It was concluded that the layup pattern of ±45°, 0°, 90° did not lend itself to be completely compacted in a closed system. Each layer of the material being orientated differently from the neighboring layers results in fibers crossing each other. The degree of matrix movement becomes limited unlike that of a unidirectional composite where fibers are permitted to move between fibers of the neighboring layers thereby forming a hexagonal fiber array when a cross section of the laminate is viewed.

At this point work was redirected by Bendix to fabrication of the piston cylinder specimen.

8.1.5.2 Piston Cylinder Specimen

Manufacturer of Cylinder

The specimen design initially requested by Hamilton Standard is shown in Figure 8-18. This layup pattern concentrated the 90° filaments toward the outer surface and 0° filament toward the inner surface.

After process evaluation of this initial design, the layup was modified to permit a dispersion of the 90° lamina throughout the wall thickness rather than concentrate them at the outer surface. The reason for this was that since the 90° layer was a constricting layer to composite movement during consolidation, advantage of the numerous forming sequences for this cylinder was taken. The 90° layer was the last layer of each processing sequence. The cylinder was built up in seven sequences, the respective order of lamina being

1. $(0_9/90)$
2 - 7. $(0_5/90)$

This was six layers less than initially desired, but deviation was permitted by Bendix since dimension of the specimen was required.

Table 8-2 summarizes the fabrication results for this specimen.

The basic tube was finally ground with diamond tooling to accept the test load fittings. Examination of the cylinder after grinding in the tapers and facing off the ends revealed lack of braze between some of the layup sequences, Figure 8-19. Although not evident during the processing, these areas were quite pronounced on a clean ground surface.

Brazing of Test Load Fittings

A process evaluation of brazing the test fittings was completed on a composite cylinder which was available from previous tube studies. The objective of this evaluation was to determine feasibility of assembling the components with the braze foil, evidence of tube bulging when heated if composite is unrestricted and wetting of the braze to the electroless nickel plated H11 steel pieces.

A review of literature in the early phase of this program concerned with brazing aluminum to steel revealed the use of coatings to enhance the wetting of steels; hot dip coating or nickel plating. The latter was selected as the procedure to employ since

this is an area in which Hamilton Standard has experience. Each set of fittings was electroless nickel plated to a thickness of approximately 0.0005 to 0.0010 inch per standard procedures.

Several operations were essential to prepare the subassemblies prior to the brazing operation. These were the plating of the H11 steel and the cleaning of the steel end fittings, as well as the composite.

Cleaning procedure of the parts was as follows:

1. Steel parts were scoured with Gibson Cleaner and water and dried at 150°F.

2. The BORSIC - aluminum tube was baked at 225°F to drive off any cooling water which may have stayed with the composite after grinding. The surfaces were wiped with methyl alcohol using clean gauze. Braze surfaces were lightly sanded with clean No. 240 grit aluminum sandpaper, sanding in one direction only. Surfaces were again solvent wiped.

Assembly went easily. Several layers of 0.003 inch each 718 Alcoa brazing foil were employed instead of one due to the fittings being slightly oversized. The Alcoa 718 was employed because it has a lower brazing temperature - 1090°F - than the Alcoa 713.

The assembly was placed into the ABAR Vacuum Furnace and the following brazing operation was performed:

1. Evacuate the atmosphere and back purge with argon. Repeat operation.

2. Draw vacuum 10^{-5} torr and increase heat to 1020°F for 15 minutes to stabilize temperature.

3. Increase heat to 1090 - 1100°F and hold for 15 to 30 minutes.

4. Cool to room temperature in vacuum.

Examination revealed good wetting to the metal surface but joints not filled completely, Figure 8-20. Distortion of the tube was limited to one layer being delaminated, but this was evident to a lesser degree prior to the brazing run. A large crack was apparent running longitudinally. The crack appeared to extend through the first sequence (10 layers), Figure 8-21. The material immediately adjacent to the crack was raised a maximum of 0.064 inch at the center of the tube to 0.030 inch at the edge of the test fittings.

8.1.6 Conclusions Concerning BORSIC-Aluminum Composites

Results of the investigations within this program indicated:

1. BORSIC-aluminum monolayer tape can be effectively employed in the fabrication of the side brace and torque arm. Employment in cylinder construction is feasible, however, additional effort is essential to place this process at the same confidence levels as the previous components.

2. The tape facilitated ease of handling and provided an excellent medium for maintaining proper fiber spacing and orientation during the brazing consolidation process. Utilization of the brazing technique permitted employment of low pressures, less than 100 psi.

3. The desired fiber volumes essential to the strength of the components was achieved in all members with the exception of the cylinder which was 10 percent less than required.

4. Evaluation of test data revealed the presence of tensile strength variation in the specimens which were subjected to various exposure times at brazing temperature.

5. Specimens fabricated and tested revealed strengths lower than those anticipated. The second side brace passed the tensile requirement and failed in compression, buckling at 13400 pound load. This specimen, however, did not possess the ideal cross sectional geometry. The torque arm failed at a lower bending load than that expected, however, the lower failure level was attributed to an error in the design of the specimens, low cross section area of the side rail, and the strength variation of the material as discussed in Item 4 above and Paragraph 5.2.1.2 (Test Results - Trail Specimens).

6. The braze joints of the specimens were of accepted quality with no fractures occurring in any of the joints.

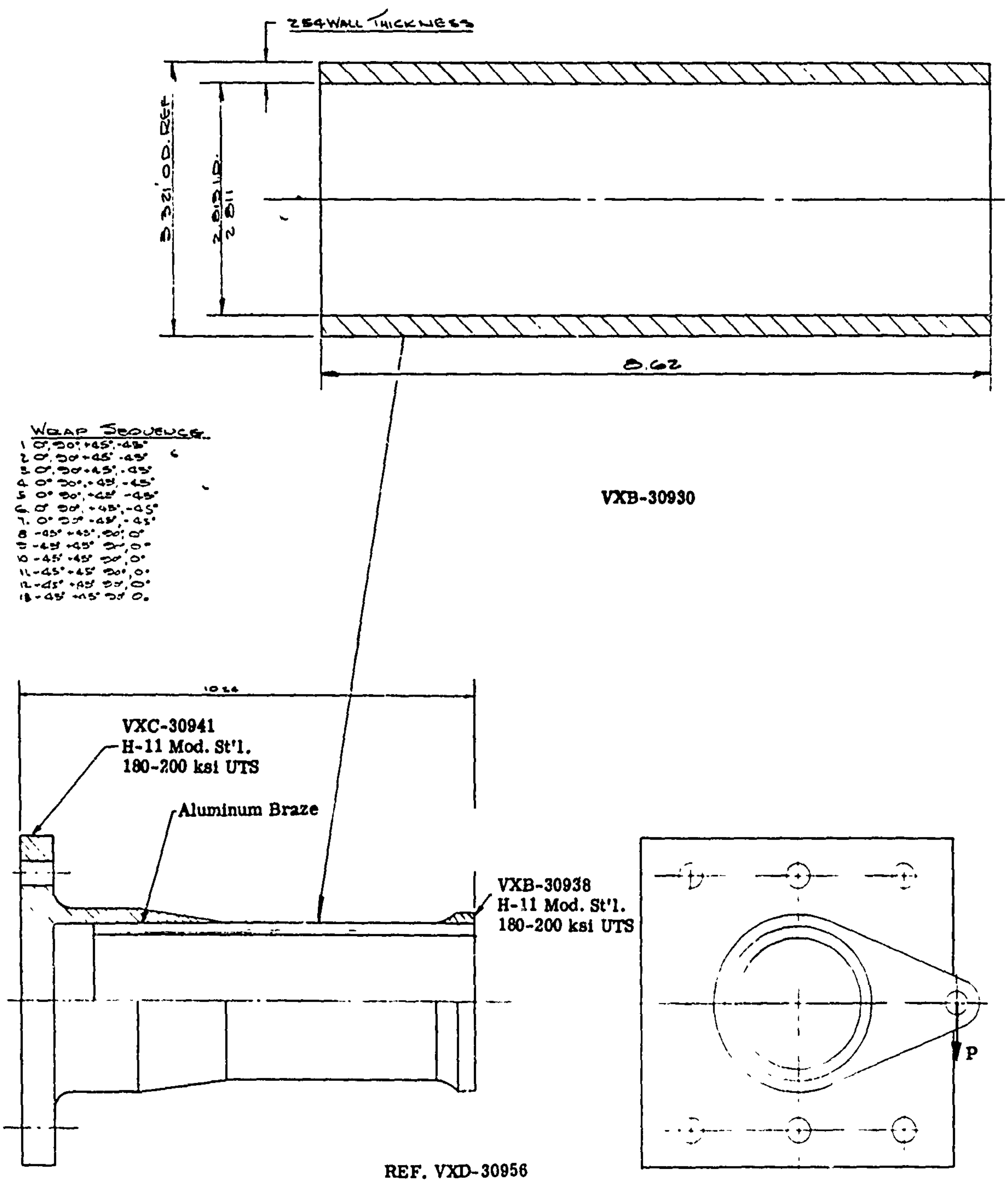


Figure 8-13. Cylinder Specimen, BORSIC-Aluminum

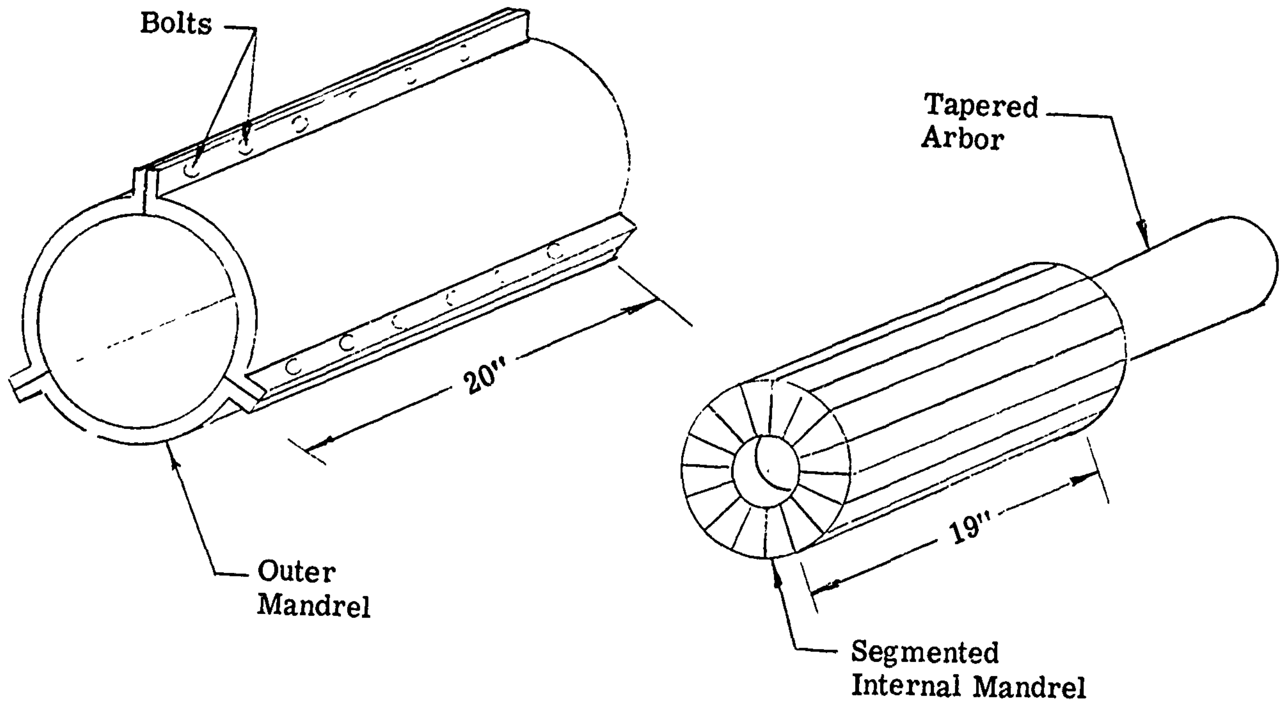


Figure 8-14. Outer and Internal Tooling Mandrels-Outer Cylinder

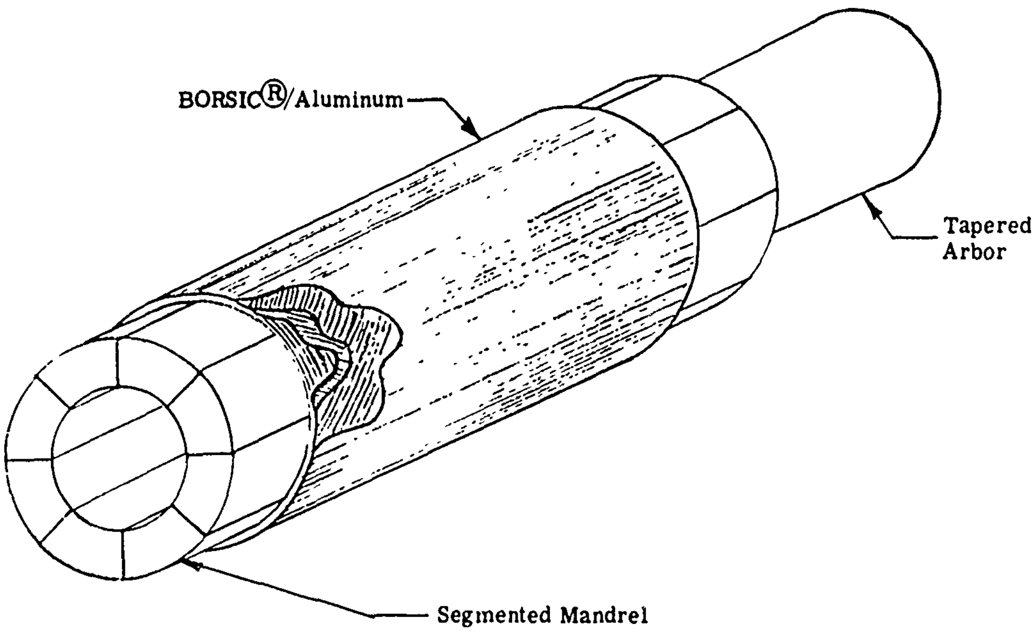


Figure 8-15. Tape Layup on Internal Mandrel

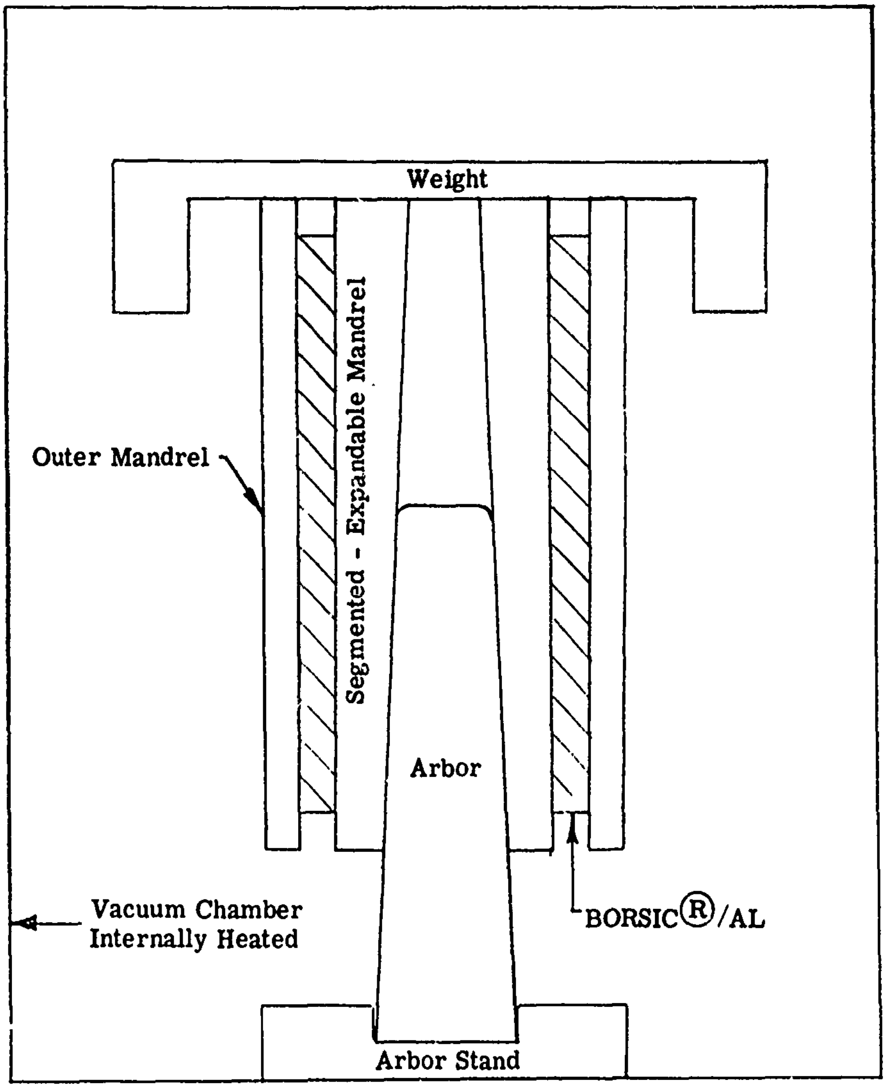


Figure 8-16. Brazing Assembly

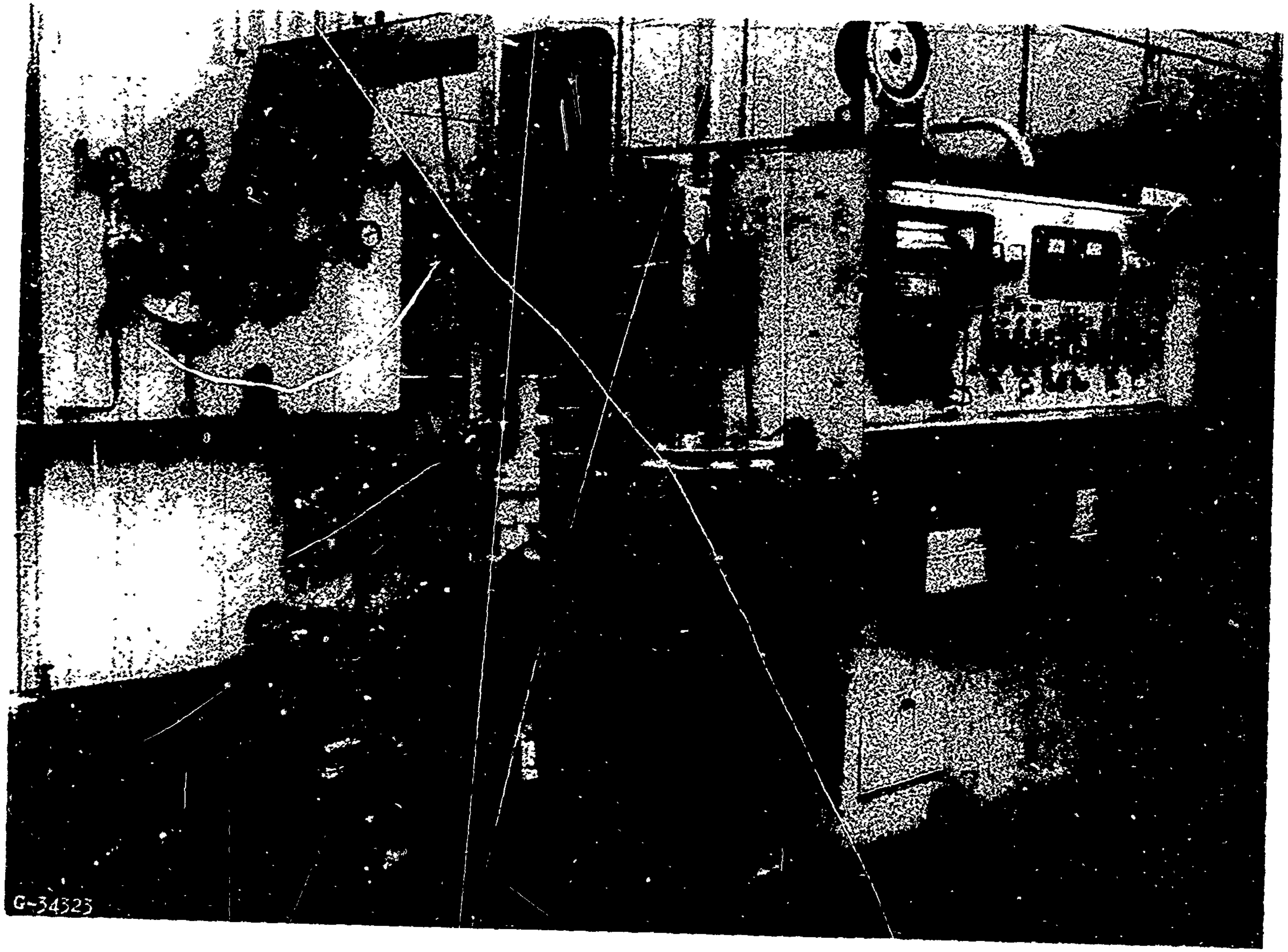


Figure 8-17. ABAR Vacuum Furnace

TABLE 8-1. PROCESS SUMMARY - OUTER CYLINDER SPECIMEN

Cylinder No.	Layup Pattern	Number of Layers Composite	Outside Diameter	Internal Diameter	Average Thickness Per Layer
#1	$(\pm 45°, 0°, 90°)_5 0°$	21	3.325	2.977 ± 0.002	0.0107
	$(\pm 45°, 0°, 90°)_2$ plus 0.002 of 713 Braze Alloy	8	2.977 ± 0.002	2.825 ± 0.005	0.0093
	(±45°, 0°, 90°) plus 0.002 of 713 Braze Alloy	4	2.825 ± 0.005	2.773 ± 0.003	0.006
#2	$(\pm 45°, 0°, 90°)_2$	8	3.336	3.206 ± 0.005	0.0081
	(±45°, 0°, 90°) plus 0.002 713 Braze Alloy	4	3.206 ± 0.005	3.142 ± 0.005	0.0075
#3*	±45°, 0°, 90° plus 0.002 Braze	4	2.841	2.791 ± 0.002	0.0057

*Compaction Pressure 4X previously used pressure.

Reference CLG-9, January 30, 1970.

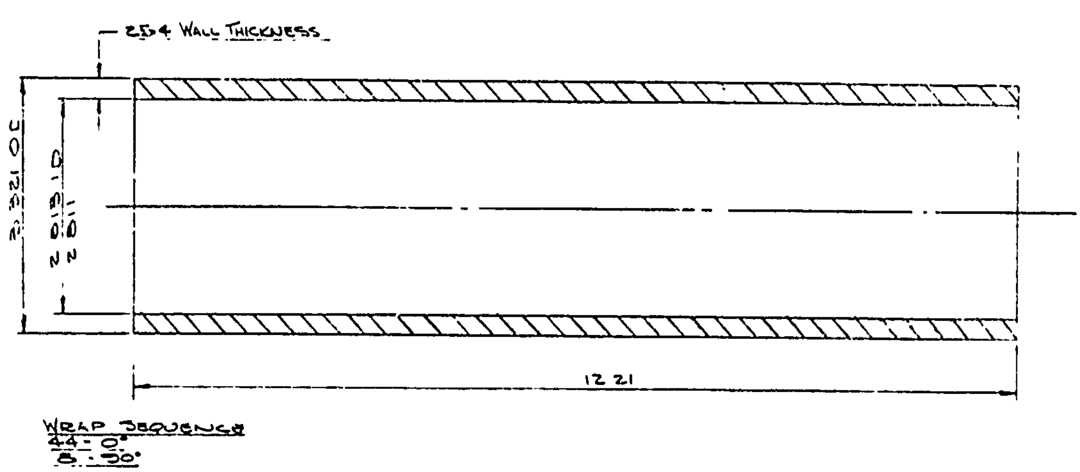


Figure 8-18. BORSIC-Aluminum Tube

TABLE 8-2. PROCESS SUMMARY - PISTON CYLINDER

Layup Sequence	Pattern No. of Layers	Inner Diameter Nominal	Outer Diameter Nominal	Measured Wall Thickness	Accumulated Average Thick/Layer	Sequence Average Thick/Layer
1	0°_9, 90 10 layers	3.324	3.208	0.059	0.0059	0.0059
2	0°_5, 90 6 layers	3.336 (1)	3.128	0.099	0.0062	0.0065
Rebrazed		3.336	3.151	0.092	0.00575	0.0046 (0055) (2)
3	0°_5, 90 6 layers	3.336	3.090	0.123	0.0056	0.0051
4	0°_5, 90 6 layers	3.336	3.013	0.164*	0.00585	0.0064*
Rebrazed		3.340	3.021	0.160	0.0057	0.0061
5	0°_5, 90 6 layers	3.340	2.946	0.193	0.00565	0.0055
6	0°_5, 90 6 layers	3.340	2.866	0.223	0.00558	0.005
7	0°_5, 90 6 layers	3.344	2.796	0.267	0.0058	0.0073

(1) Outer diameter grew 0.012 due to outer mandrel being improperly assembled.
(2) Corrected for growth.
* Not fully compacted due to binding of internal mandrel and arbor.

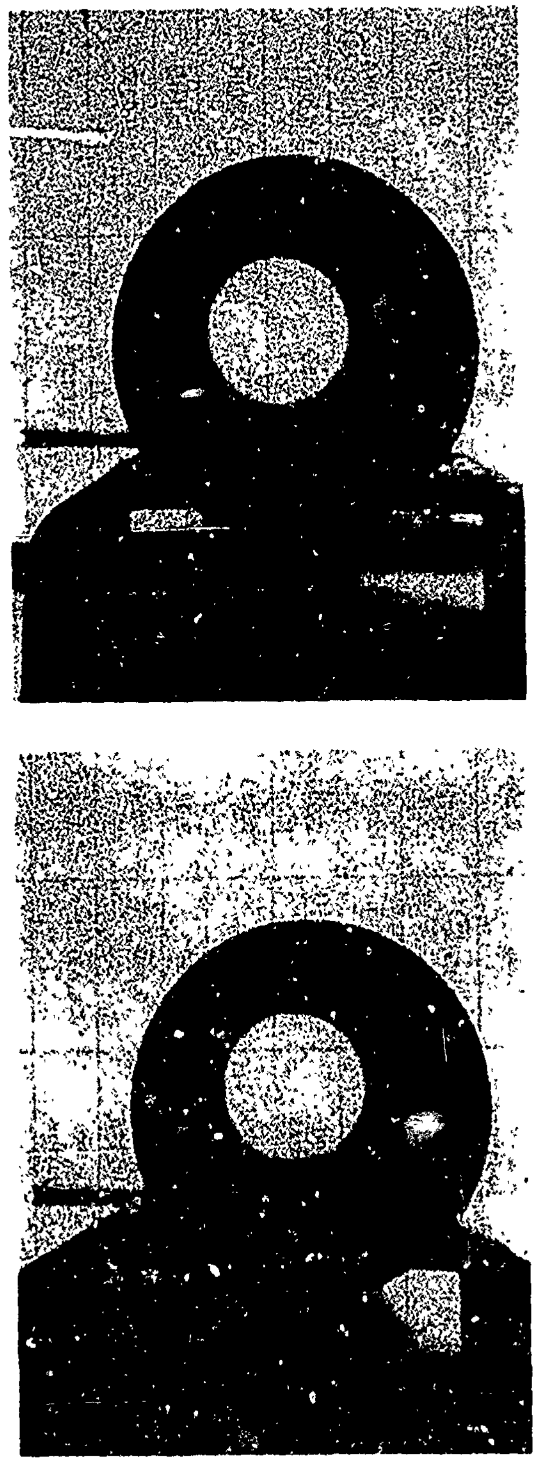


Figure 8-19. BORSIC-Aluminum Test Specimen

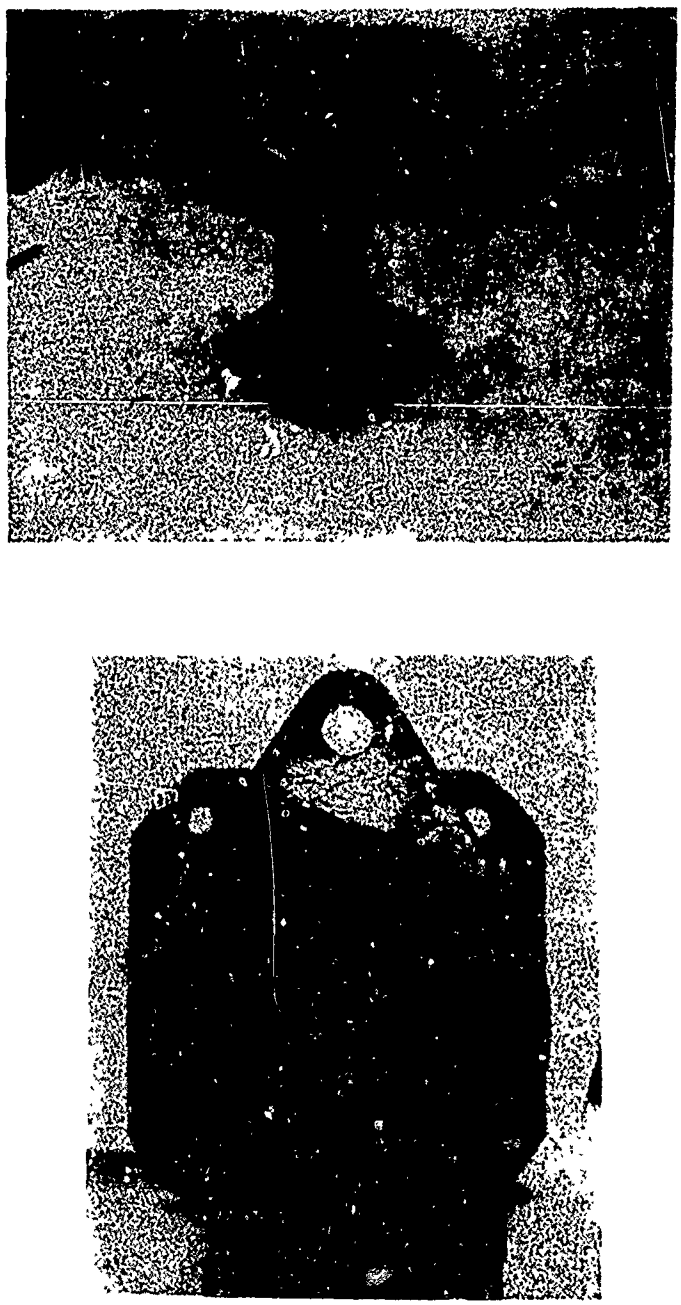


Figure 8-20. Process Specimen

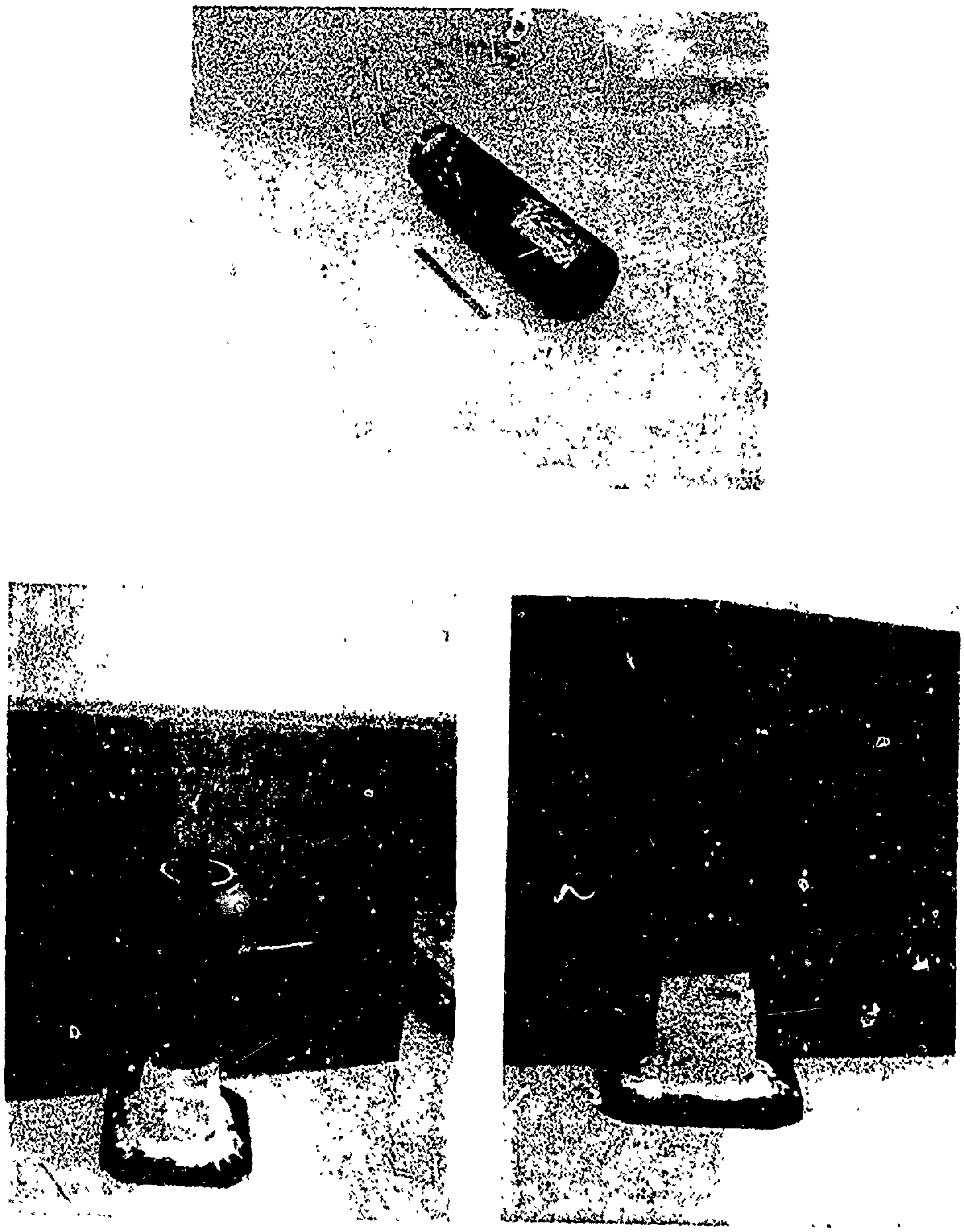


Figure 8-21. BORSIC-Aluminum Test Specimen

8.2 BORON-EPOXY COMPOSITE

8.2.1 Fiber and Broad Goods Sources

Fiber History

The 0.004 inch diameter fibers for this program were furnished by the Air Force. The fibers were first shipped to the 3-M Company on December 6, 1968 under Air Force Contract No. F33615-69-C-0048. A total of twenty pounds of these fibers were then allocated for use on Phase I of this program. Ten pounds of fibers were shipped to both Hamilton Standard and Hercules/ABL.

Hercules did not receive Q.C. papers with the fiber shipment from 3-M and therefore contacted the fiber vendor (Hamilton Standard) to obtain quality control data on the spools of boron received and the boron filament specification in effect when the filament was produced. Quality control data furnished by Hamilton Standard to Hercules is presented below.

Item: Boron Filament

Quantity: Ten Pounds

Contract: Shipped to 3M Company on December 6, 1968 under Air Force Contract No. F33615-69-C-0048.

Characteristics:

Diameter: 0.0039 ± 0.0002 inch

Average Tensile Strength of Test Specimens:

Spool No.	UTS (ksi)
6407	422
6408	447
6409	439
6461	408
6462	446
6463	449
6635	485
6636	439
6637	409
6704	440
6705	454
6706	455
6707	433
6708	438
6815	415
6816	437
6817	453
6824	428
6825	446
6826	457

Processing of Boron-Epoxy Broad Goods

Hercules produces broad goods by winding the boron fiber into the resin on a large drum. During the winding process the fiber is coated with a cured resin sheath which aids fiber alignment and prevents fiber to fiber contact in the composite. The BP-907 resin is purchased as a laminating adhesive film, 0.020 ± 0.002 pound/foot^2 with release paper on one side and a polyethylene film on the other side. The film is placed on the drum and the polyehtylene is removed so the boron can be wound into the resin. The winding operation is machine controlled to produce a fiber count of 216 per inch. The preliminary resin sheath insures a minimum fiber spacing of 0.2 mils. The materials are then cured with a vacuum bag process to produce the finished broad goods.

8.2.2 Boron-Epoxy Pin Bearing Specimens

These items are illustrated in the discussion on testing, Appendix D.

Two types of pin bearing specimens were built: the first incorporates 45° cross-ply reinforcements, the second incorporates spiral wound reinforcements.

Spiral Wound Reinforcement - The fabrication tool shown in Figures 8-22 and 8-23 was designed and built for use in winding trials of spiral wafers.

Fabrication trials were conducted using monofilaments of boron with the BP-907 resin system in an attempt to achieve hole diameters down to 1/2 inch. The results indicated that prepreg spiral wound boron wafers with a hole diameter of 5/8 inch or larger are feasible. Wafers with hole diameters less than 5/8 inch are not recommended for fabrication with boron wire diameters of 0.004 inch and larger. The finished product is shown in Figure 8-24.

A closed metal mold was designed for the fabrication of these test specimens. The mold closes to a fixed set of stops to control the thickness of the specimen, Figure 8-25. The width of the test specimens is 1.2 inches. The distance from the centerline of the pin hole to the nearest corner is one inch. This dictates that the size of the spiral wafer be one inch radius or two inches outside diameter. The sides of the spiral wafer are not cut until the specimen has been completely cured. The mold width is therefore two inches and the excess material is removed from the sides of the specimen, after cure, by a diamond cutoff wheel.

The general method of processing the flat plate specimens is similar to that used for the tubular specimens. The following process was used to fabricate the flat plate specimens.

1. Apply release agent to the mandrel. Tool tryout PBE-0 and specimen PBE-1 used a spray coat on the mandrel, whereas specimens PBE-2, PBE-3 and PBE-4 used a Kapton release film. (Reference Appendix D.)

2. Remove release paper from one side of broad goods oriented for 0_2°.

3. Insert in mold.

4. Remove release paper from sides of spiral wafers.

5. Insert at ends of mold.

6. Remove release paper from side of 0_2° fill.

7. Insert in mold between spiral wafers.

8. Remove release paper from one side of broad good oriented for 0°.

9. Insert in mold.

10. Consolidate layup by application of vacuum bag and heat lamps.

11. Remove vacuum bag.

12. Repeat steps 2 through 11 until desired number of lamina is obtained.

13. Install top of metal mold and place in vacuum bag.

14. Press cure as follows:

    a. Place assembly in a press and set for 200 psi on mold.

    b. 730 mm Hg vacuum on vacuum bag.

    c. 180-190°F 1/2 hour.
    280-290°F 1/2 hour.
    350-360°F 1 hour.

    d. Allow to cool down to 200°F with vacuum and pressure.

    e. Remove part when temperature is below 120°F.

15. Disassemble mandrel assembly.

16. Inspection.

The specimens were sent to Bendix for drilling of the holes. The pin holes were drilled approximately 0.060 inch undersize using an aluminum tube, No. 80 boron carbide grit, and kerosene as a carrier. The holes were finished to size using a 60,000 rpm grinder with a diamond mounted point.

45° Cross-ply Reinforcement - The same mold and process as described above for the spiral reinforced specimen was used for fabricating the cross-ply specimen. Layers of 0° and ±45° broad goods were cut to fit the mold cavity. The mold assembly, loaded with the required number of lamina, was processed by the vacuum bag and press method. The width of the specimens, as removed from the mold, was two inches wide and a trimming operation was required on both sides to obtain the 1.2 inch width.

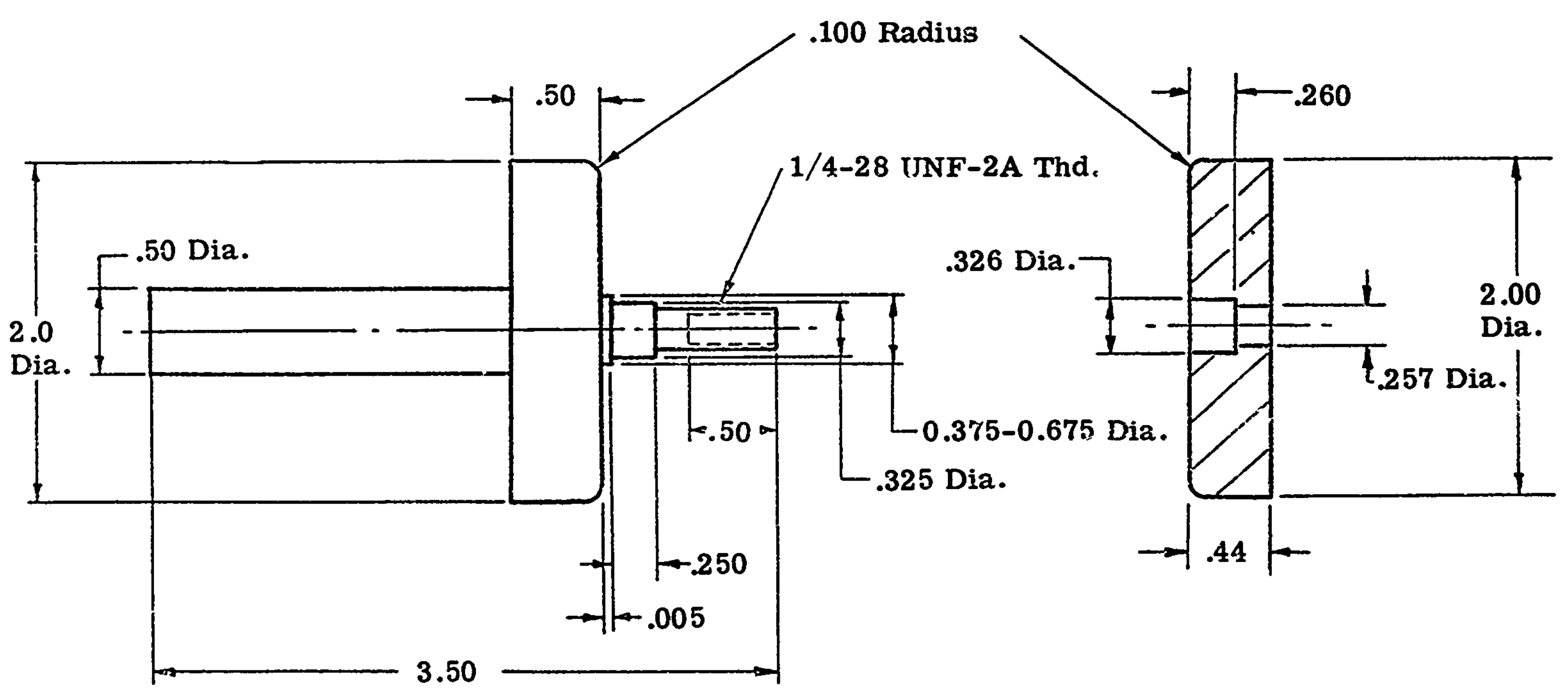


Figure 8-22. Boron Wafer Fabrication Tool

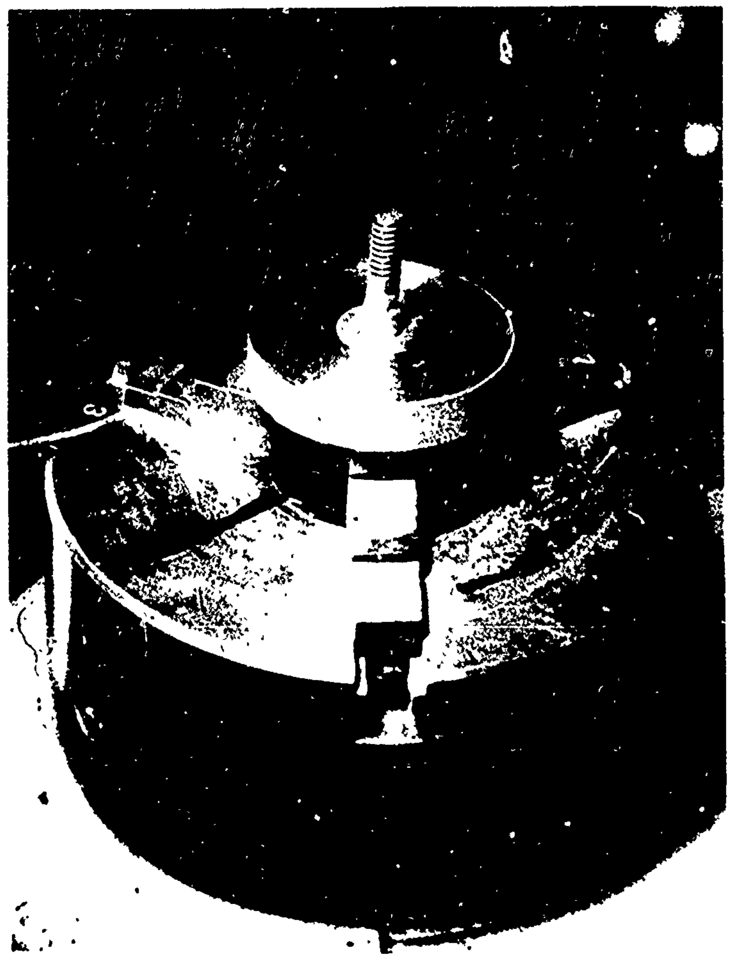


Figure 8-23. Boron Wafer Fabrication Tool

Figure 8-24. Finished Spiral Wafer

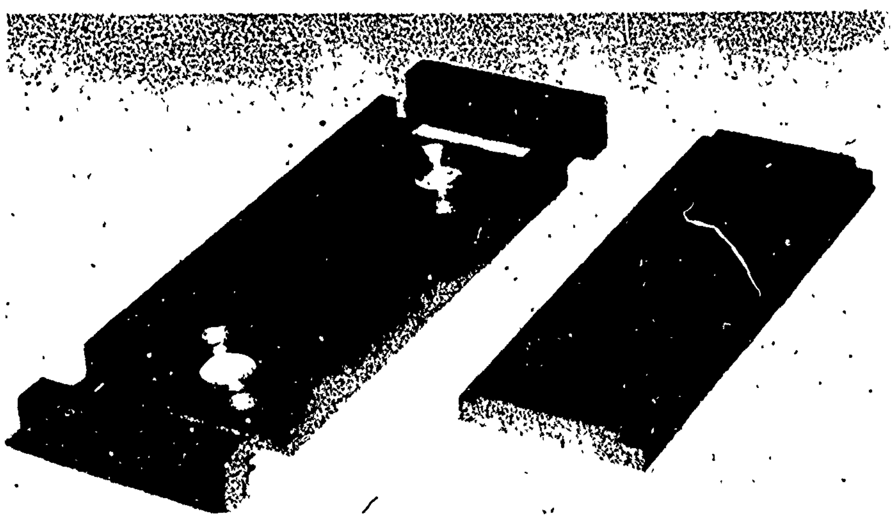


Figure 8-25. Specimen Mold

8.2.3 Fabrication of Boron-Epoxy Side Brace Components

The fabrication of both the trial specimen and the prototype assembly are described.

8.2.3.1 Side Brace Trial Specimen

This component is illustrated in Figures 8-26 and 8-27. The design details and structural test results are described in Paragraph 5.3.1.1.

Materials

Boron BP-907 Broad Goods (2002B)

Teflon Coated Glass Scrim (TX-1040)
Pall Flex Products Corporation, Kennedy Drive, Putnam, Connecticut.

Teflon Coated Glass Cloth (Armalon 95-604)
E. I. DuPont

Boron Filaments - Hamilton Standard

High Strength Adhesive (FM 1000 - 0.050 lb./ft.^{2})
American Cyanamid Company

Adhesive Primer (BR-1009)
American Cyanamid Company

Sheet Resin (PB-907-104A - 0.020 lb./ft.^{2})
American Cyanamid Company

Adhesives (Epon 871) (Epon 826) (Epon 953B)
Shell Corporation

Phenolic Microballoon (BJO-0930)
Union Carbide Corporation

Mold Release (Frekote 33)
Frekote Inc., 2300 N. Emerson Avenue, Indianapolis, Indiana

Vacuum Bag (0.002 Inch Nylon Film)

Procedure for Winding Continuous Band

An aluminum mandrel was fabricated with side panels extending approximately 0.150 inch past the periphery of the mandrel.

The mandrel was coated with a mold release (Frekote).

A sheet of BP-907 resin was installed on the periphery of the mandrel and boron was wound full width.

1. Part was wound in the following order after first layer.

Resin Paper:

2 & 3 - No resin.

Resin Paper:

4 & 5 - No resin.

Resin Paper:

6 & 7 - No resin.

Resin Paper:

8 & 9 - No resin.

Resin Paper:

10 & 11 - No resin.

Resin Paper:

12 & 13 - No resin.

Resin Paper:

14 & 15 - No resin.

Resin Paper:

16 & 17 - No resin.

Resin Paper:

18 & 19 - No resin.

Resin Paper:

20 & 21 - No resin.

Resin Paper

The part was compacted after each sheet of resin and the mandrel was cooled to room temperature before winding the next layer.

The band was removed from the winding mandrel and installed in the curing mandrel with the center removed ready for installing of the precut honeycomb.

Honeycomb Preparation

The honeycomb (23 lb./ft.^{3}) was machined to the proper final dimensions except for width; i.e., 0.867 inches high by 3.965 inches long x 1.460 inches wide.

Two pieces of broad goods were cut to the following dimensions and press cured: 1.75 inches long by 4.25 inches wide.

Honeycomb was vapor degreased using Tri-clean.

Masking tape was applied to the center 3.215 inches of the honeycomb. A vacuum bag was applied around the top part of honeycomb.

Bottom of honeycomb was submerged in microballon/epoxy mixture, vacuum was drawn pulling microballon mixture up through the honeycomb. Part was cured at room temperature for 24 hours. Excess cured microballon was removed from the part.

The microballon mixture is as follows:

Epon 871 - 35 gms
Epon 826 - 34.8 gms
Epon 953B - 10 gms
BJO - 0930 - 20.2 gms

After excess microballon was removed, part was degreased again using vapor degreaser.

BR-1009 tack primer was applied to the honeycomb and 90° broad goods.

FM-1000 was installed on each side of honeycomb and 90° broad goods placed over the adhesive.

Part was installed in press and cured at 350°F and 30 psi for one hour. Part was cooled while maintaining pressure.

Honeycomb Installation

The honeycomb assembly was inserted, then one ply of 90° boron was placed on top of the flat section of the band the length of the honeycomb.

Side and top plates were installed and Armalon and vacuum bag installed. (Clamps were used to hold side plates and top plate after vacuum bag was installed.)

Part installed in autoclave and cured: 1/2 hour at 180°F
1/2 hour at 280°F
1 hour at 350°F and 50 psi.

Part cooled under pressure to 150° before removing from autoclave.

Part removed from mold and machined to drawing dimensions, Figure 8-26.

Final Assembly

At this stage the specimen comprised a subassembly consisting of a boron filament band supported by a honeycomb core. This subassembly was shipped to Bendix where it was inspected and found to be within print dimensions. The metal fittings and bushings were then installed as follows.

1. The end fittings were assembled and potted in the urethane as indicated in Figure 8-27.

2. Bushing holes were reamed to size.

3. Bushings were pressed into metal end fittings.

4. Bushing ends were flared in a 3 1/2 inch press.

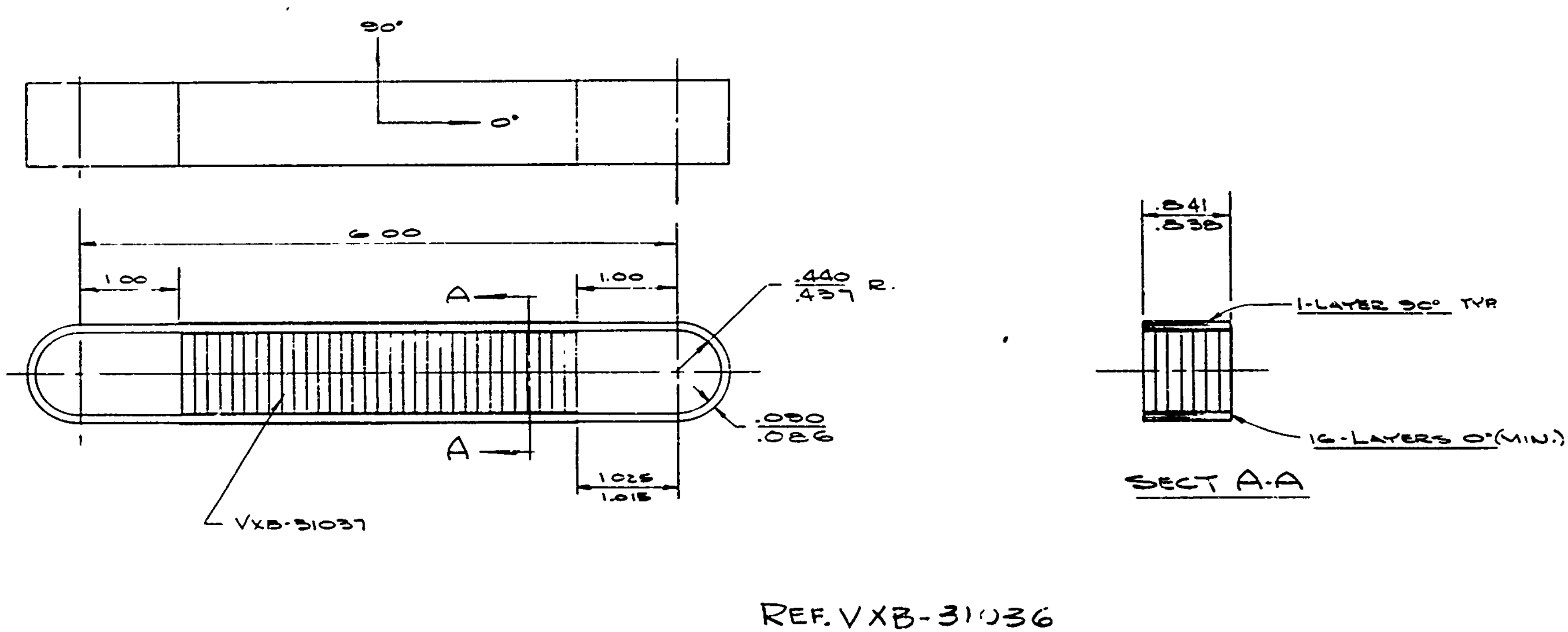
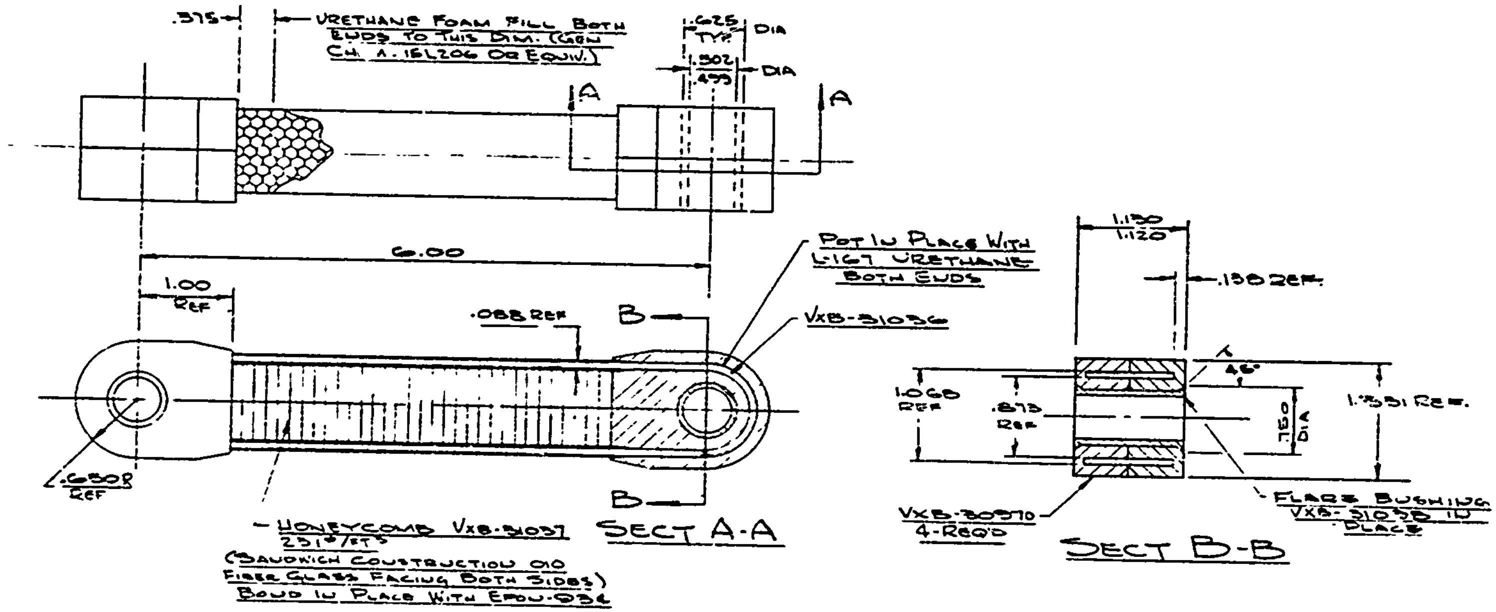


Figure 8-26. Boron-Epoxy Side Brace Specimen



Ref. VXB-30985

Figure 8-27. Boron-Epoxy Side Brace Specimen

8.2.3.2 Boron-Epoxy Side Brace Assembly

The design details concerning this item are discussed in Paragraph 5.3.1.1.

The basic composite components were fabricated by Hercules. Bendix effort dealt with procurement of the conventional metallic fittings and assembly at all parts into the final brace assembly.

1. Hercules Activities

Upper Member - This item is illustrated in Figures 8-28 and 8-29. The fabrication details are summarized below and the tooling illustrated in Figures 8-30 to 8-39, inclusive.

FABRICATION DETAILS - UPPER MEMBER

1. Fabricate chopped graphite insert (2).
   a. Prepare mold.
   b. Place chopped prepreg into mold.
   c. Cure.
   d. Remove from mold.
   e. Machine to size.
2. Machine honeycomb.
   a. Melt polyehtylene glycol and fill honeycomb cells.
   b. Machine honeycomb using milling machine.
   c. Heat honeycomb to remove polyethylene glycol.
   d. Wash honeycomb with hot water.
   e. Vapor degrease.
3. Boron Faceplates.
   a. Cure single ply boron in press.
   b. Remove and cut to shape 2" long x 10.580" wide (2 pieces).
4. Urethane filling.
   a. Using mylar self sticking tape, mask off all areas which are not to be filled with urethane.
   b. Fabricate nylon vacuum bag such that one face of the honeycomb is exposed.

c. Mix the urethane.

d. Place urethane mixture in shallow pan.

e. Connect vacuum pump to honeycomb.

f. Dip honeycomb face in urethane and let vacuum pump pull the urethane into the cells completely filling them.

g. Let the urethane cure and disassemble.

5. Prepare for bonding.

a. Cut honeycomb for chopped graphite insert.

b. Vapor degrease.

c. Insert hardpoints (chopped graphite insert).

d. Place FM 1000 over assembly.

e. Place cured facesheets on honeycomb.

6. Cure

a. Place honeycomb assembly in jig to insure parallel faces.

b. Place in press and cure at 350°F and 25 psi for 1 hour.

c. Remove from press.

7. Fabricate boron belt.

a. (The amount of boron within this assembly was 17 plies instead of the minimum 14 plies, still maintaining the required thickness of 0.074 inch maximum.) Remove from forming jig and place on curing jig with metal end pieces.

b. Place honeycomb and inserts within the boron composite.

c. Cut two pieces boron, 1059 inches wide by 2.00 inches long.

d. Place these pieces on outside of boron belt over the honeycomb.

8. Cure

a. Place side plates on unit.

b. Place top plate on fixture.

c. Place Armalon over entire unit.

d. Place thermocouple in unit.

e. Place vacuum bag over unit.

f. Use clamps to hold side plates against composite.

g. Place unit in autoclave.

h. Cure at the following conditions:

(1) Maintain full vacuum.
(2) Maintain 50 psi pressure in autoclave.
(3) Raise temperature to 180°F for 1/2 hour.
(4) Raise temperature to 280°F for 1/2 hour.
(5) Raise temperature to 350°F for 1 hour.
(6) Lower temperature to room temperature before releasing pressure or vacuum.

i. Remove part from autoclave.

j. Disassemble.

9. Machine parts to final dimension.

NOTE: Two upper side braces will be machined from one layup.

10. Perform dimensional inspection.

11. Prepare documentation.

12. Ship to Bendix.

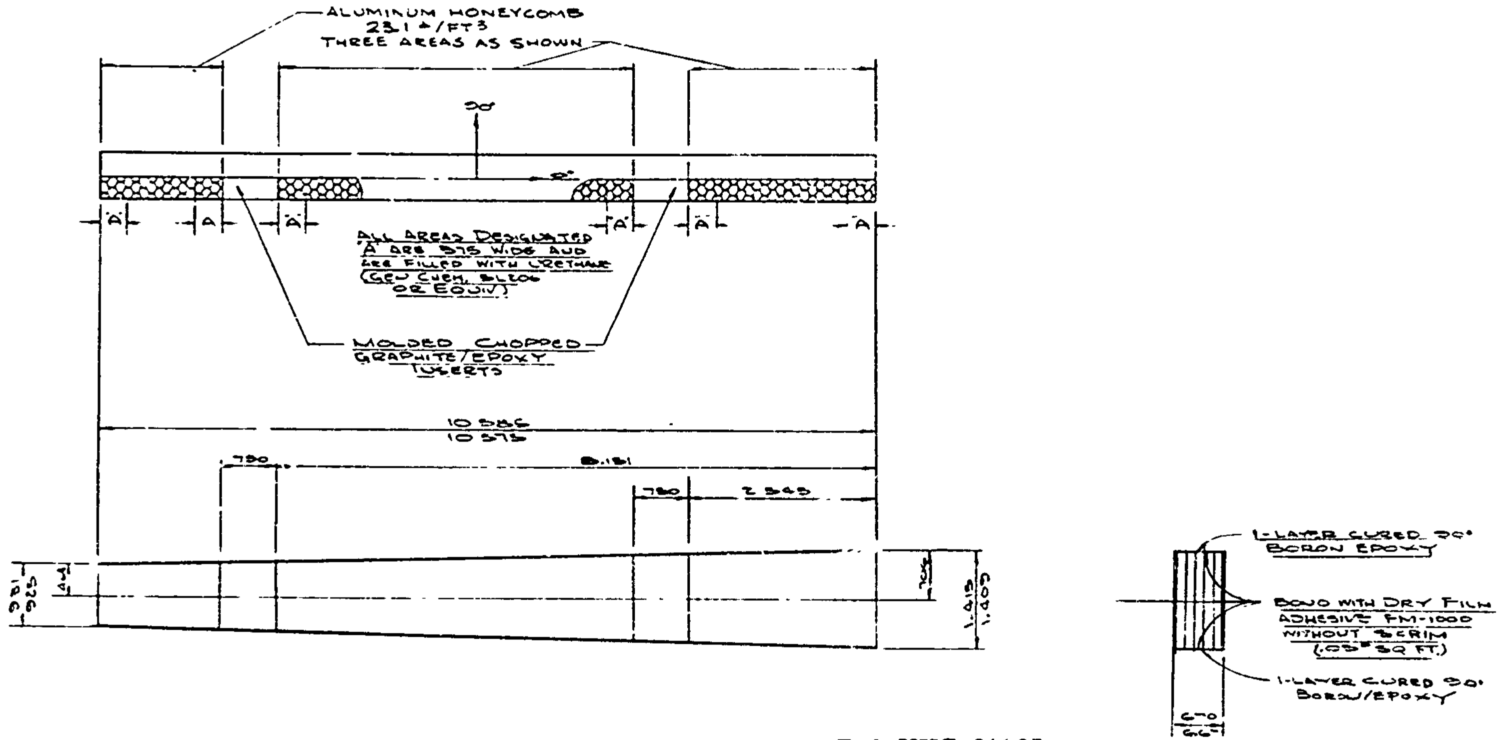


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Figure 8-28. Upper Side Brace, Honeycomb Core

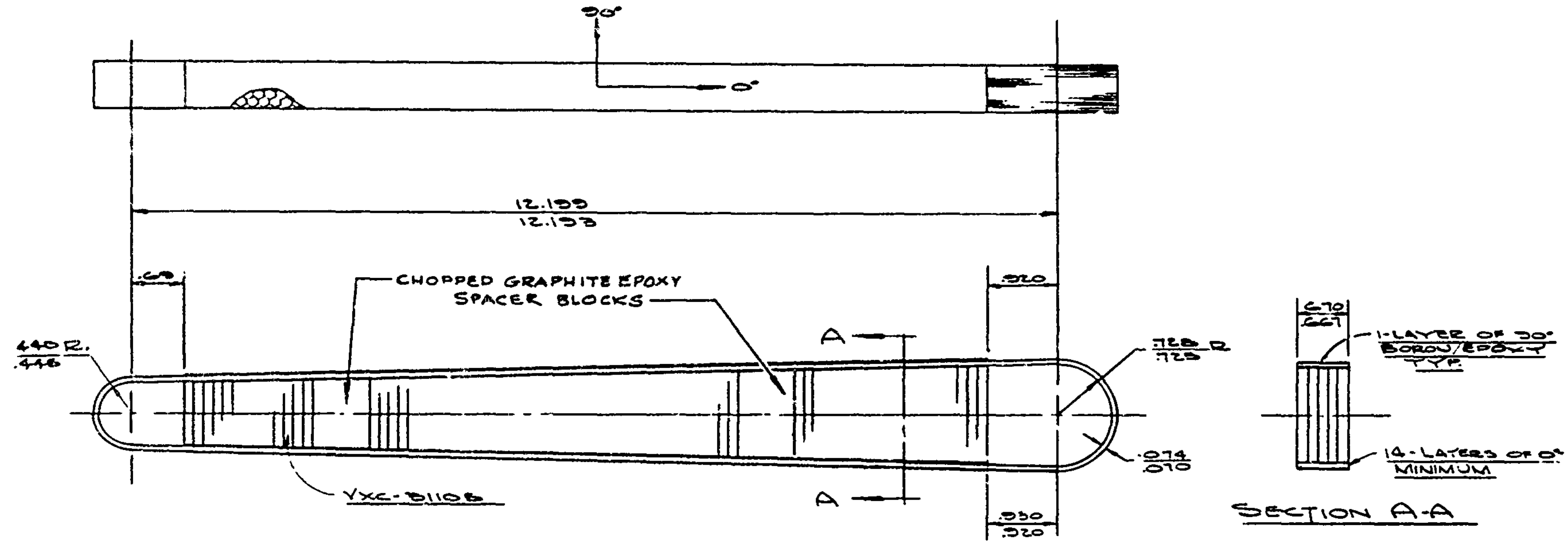

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Figure 8-29. Upper Side Brace Flange Assembly

Figure 8-30. Upper Side Brace Tooling

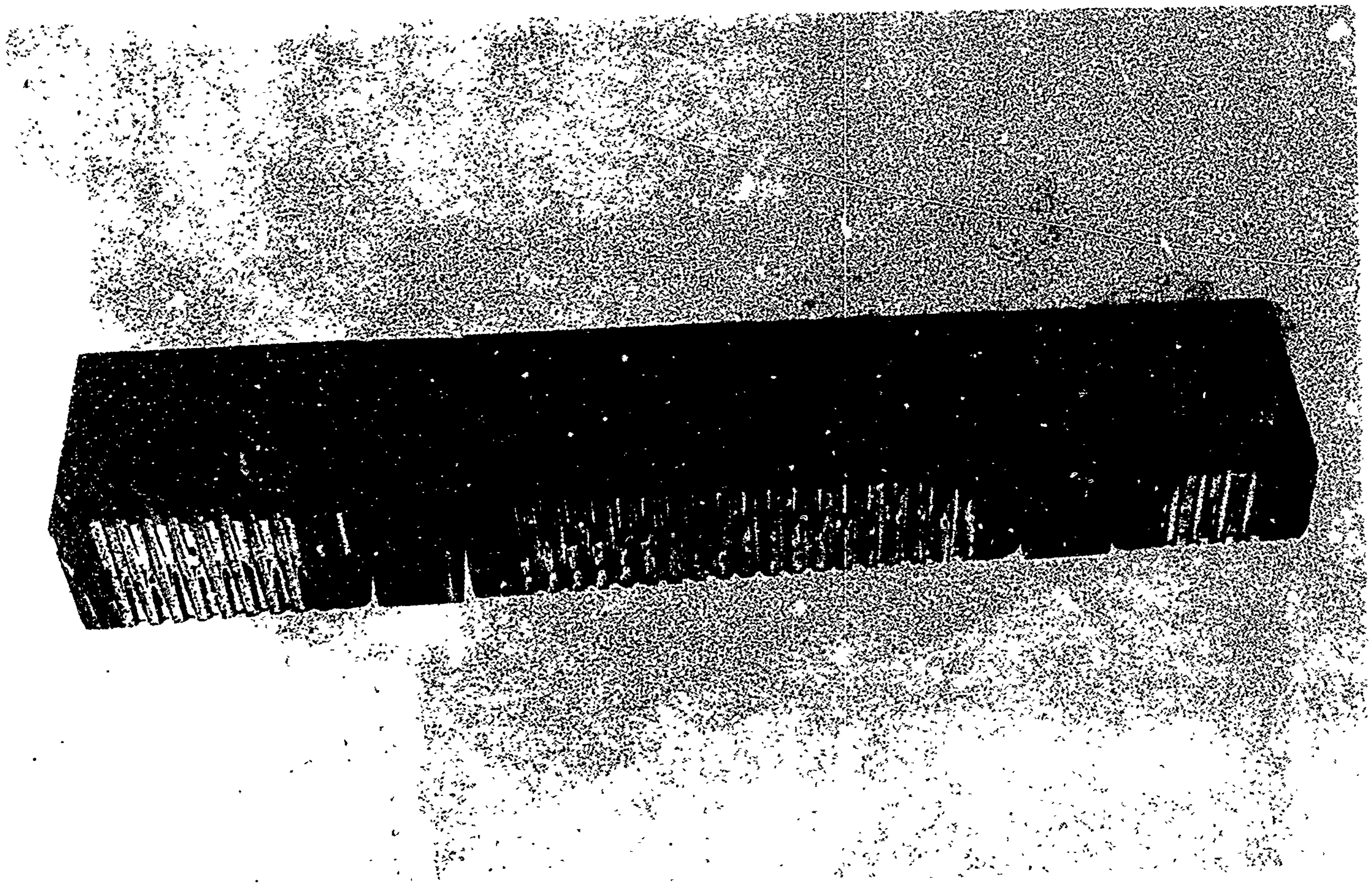

Figure 8-31. Microballoon Filled Honeycomb and Graphite Hardpoints, Upper Brace

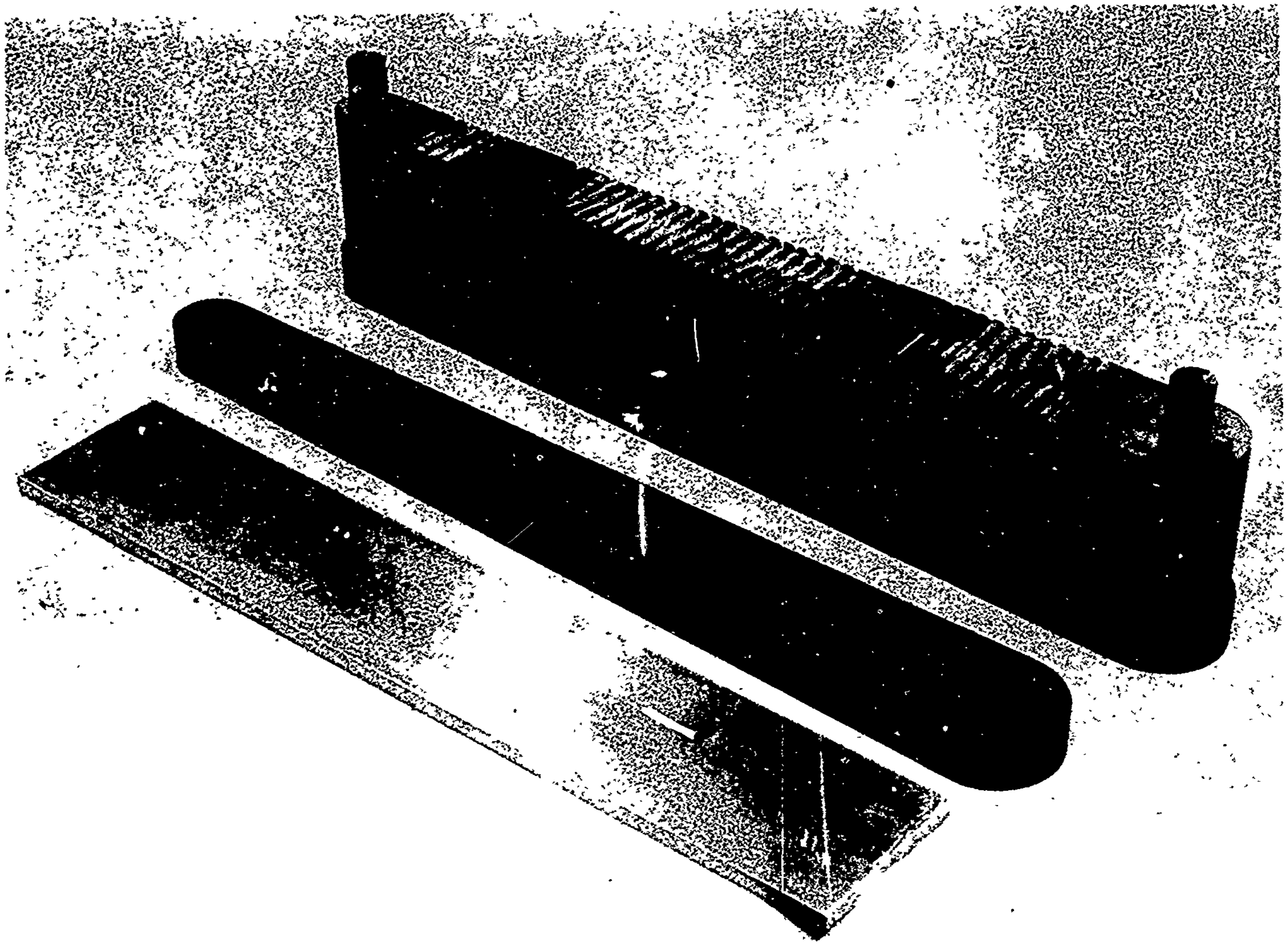

Figure 8-32. Upper Brace Tooling, Partially Assembled Core

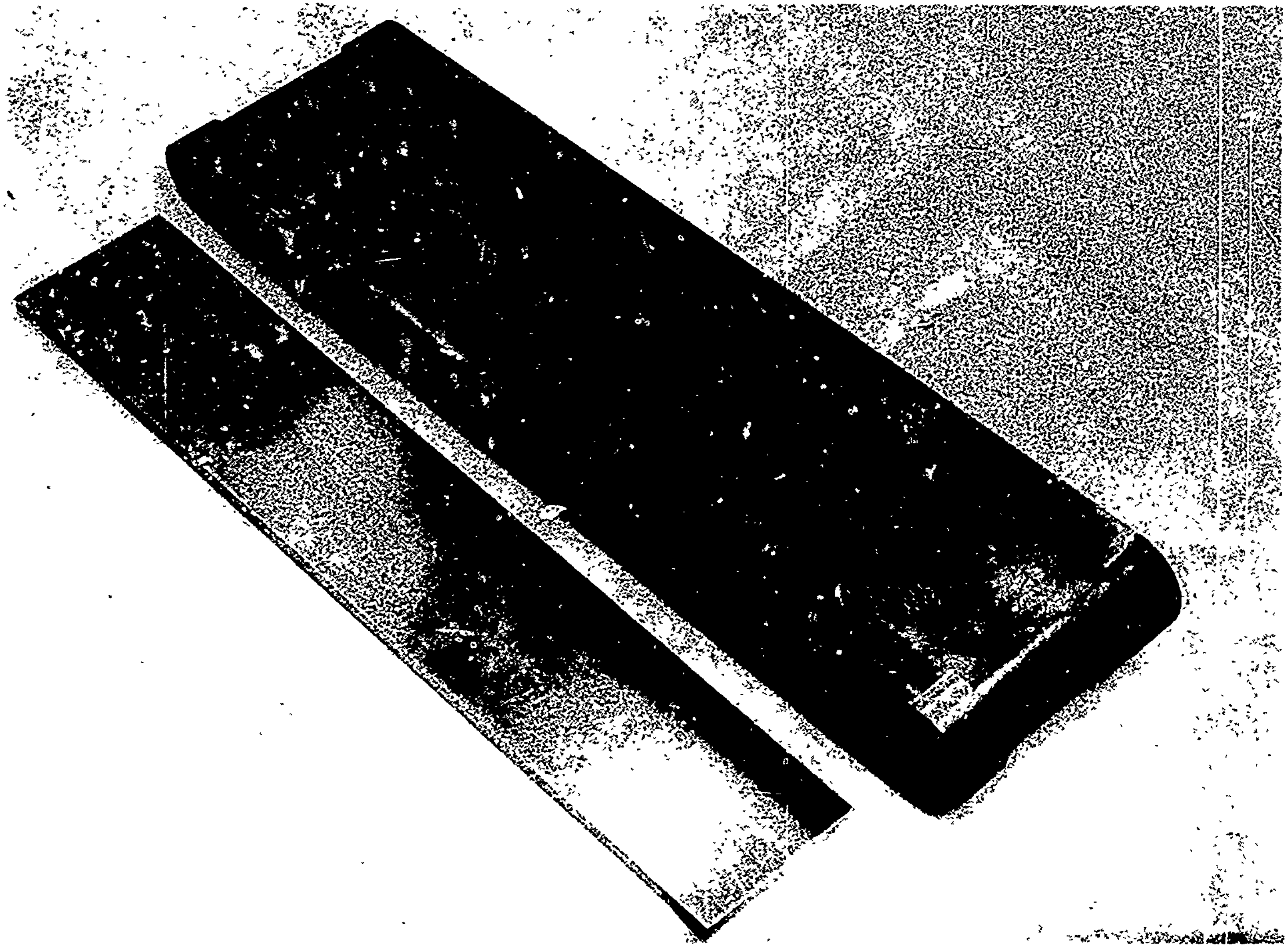

Figure 8-33. Upper Brace Tooling with Honeycomb Core

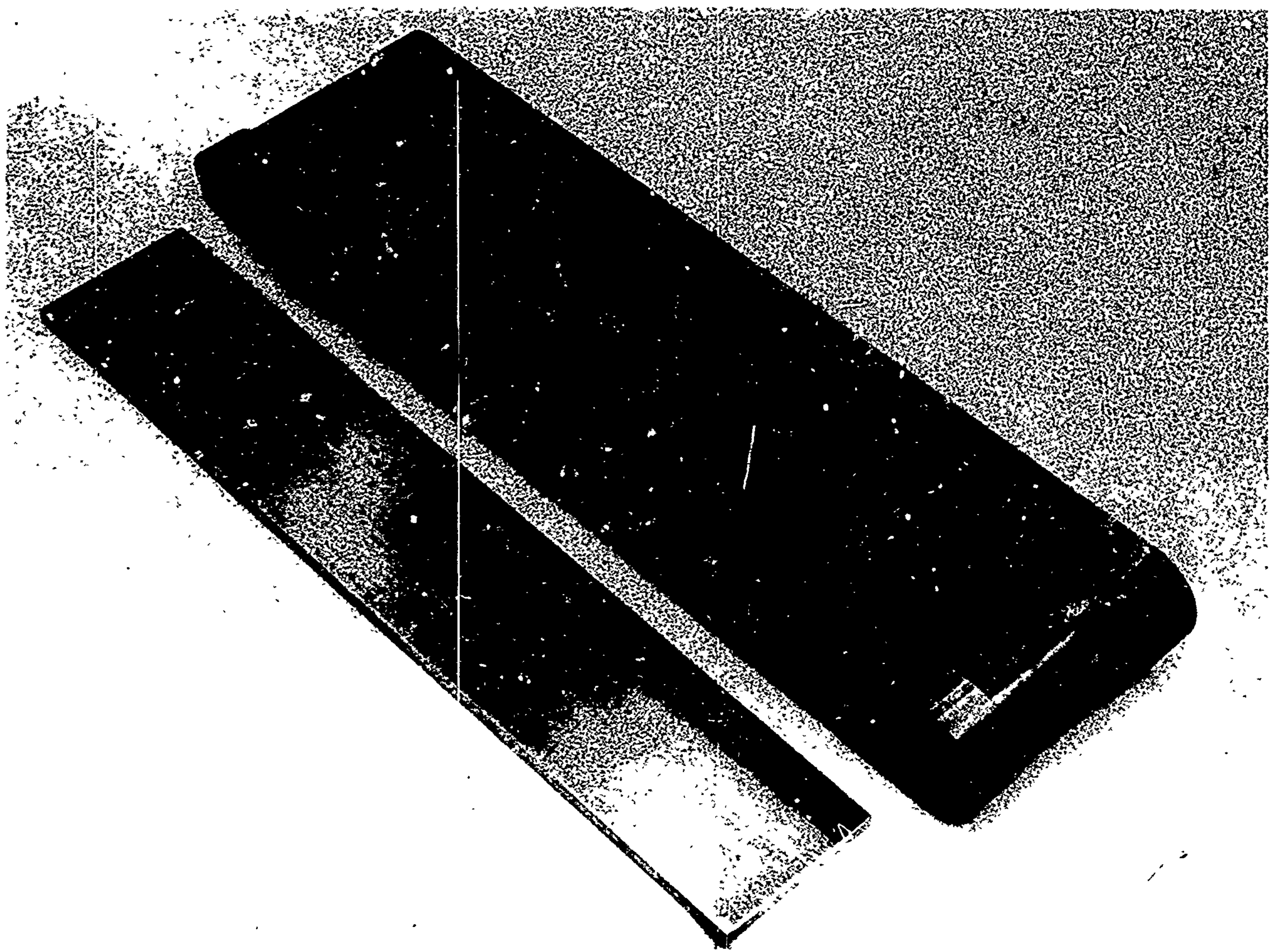

Figure 8-34. Upper Side Brace Tooling, Boron Ply Over Honeycomb Core

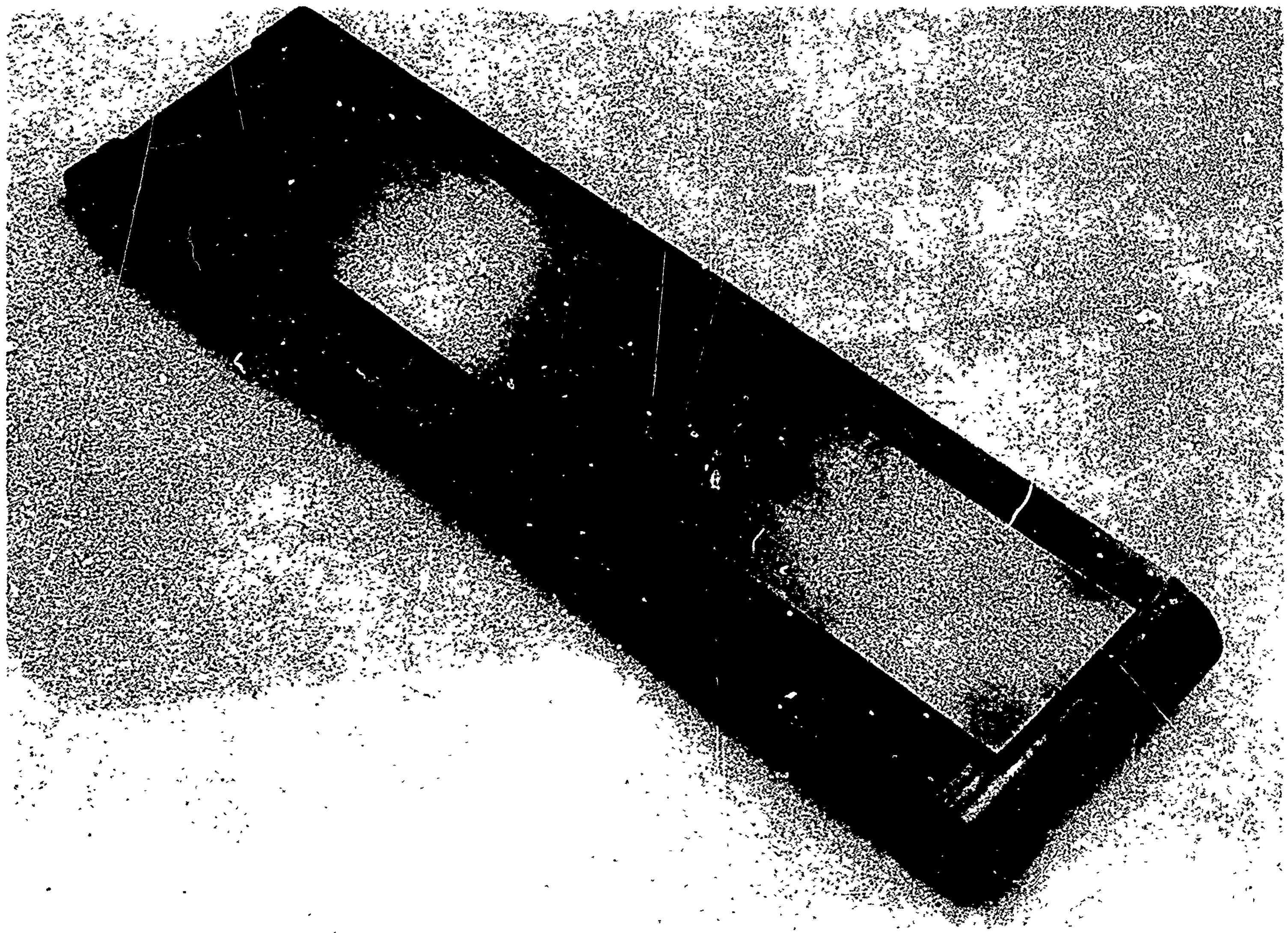

Figure 8-35. Upper Side Brace Tooling, Caul Plate in Place

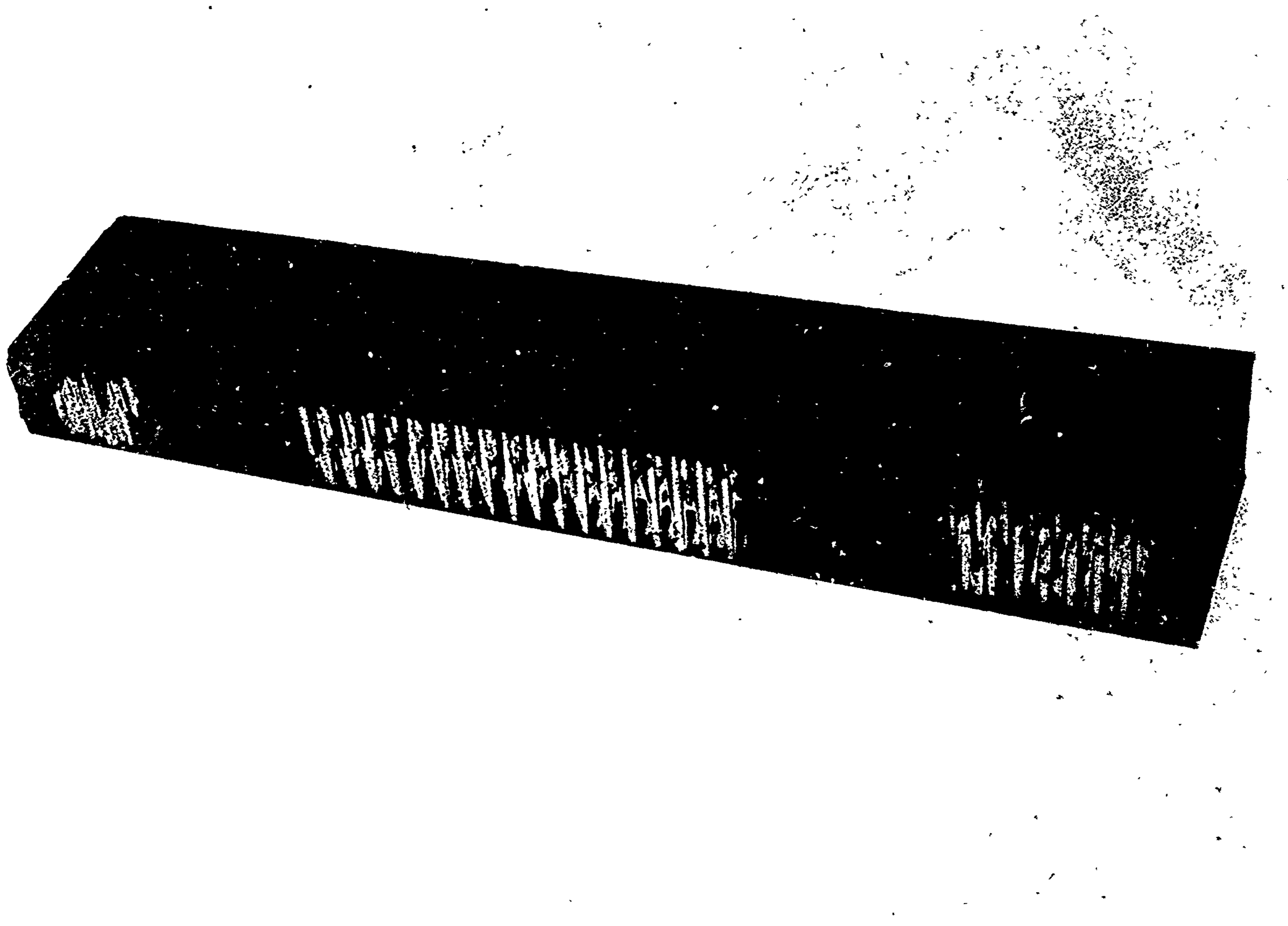

Figure 8-36. Completed Honeycomb Core, Upper Brace

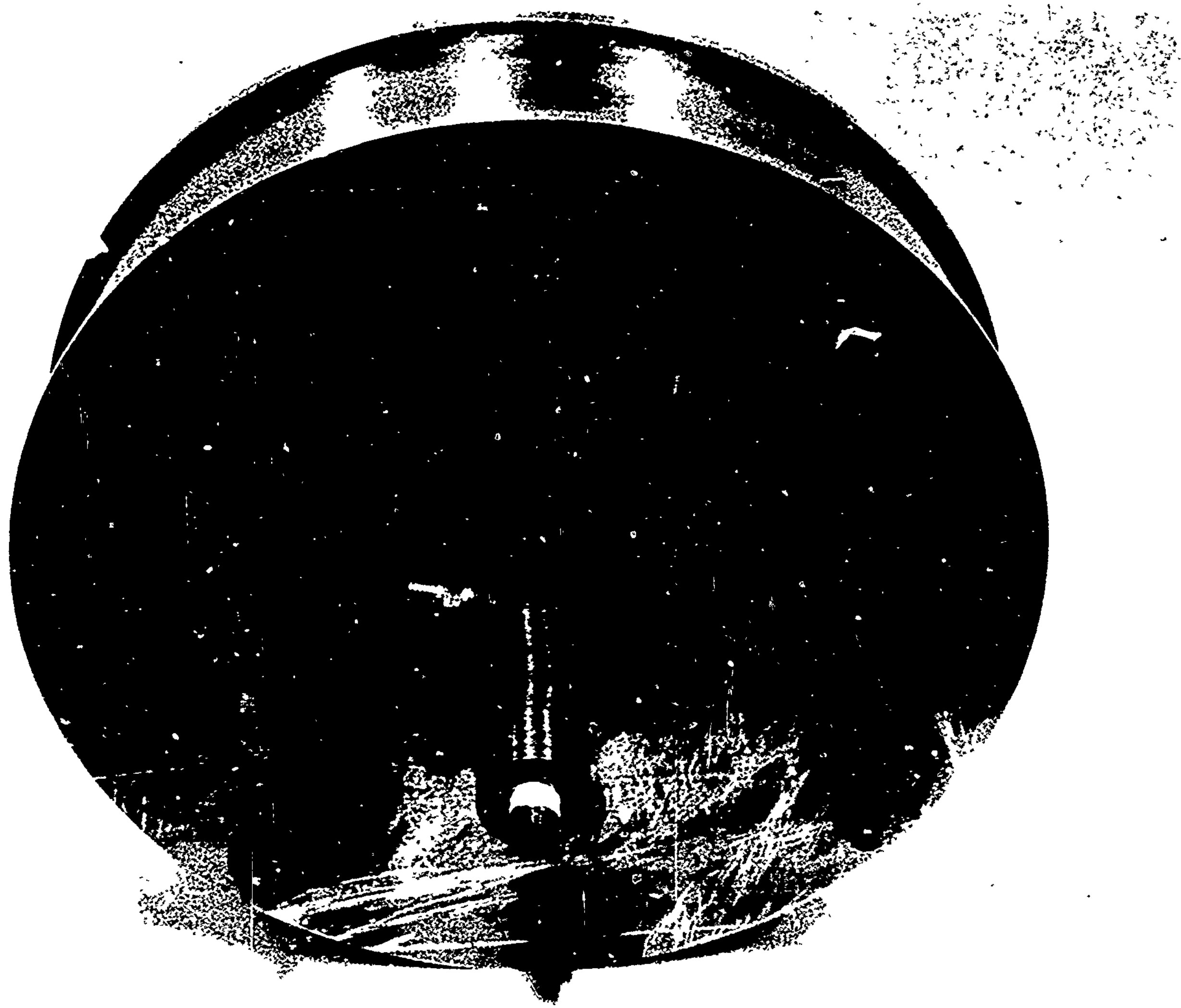

Figure 8-37. Upper Side Brace, Boron Strap Preform Mandrel, Vacuum Piping

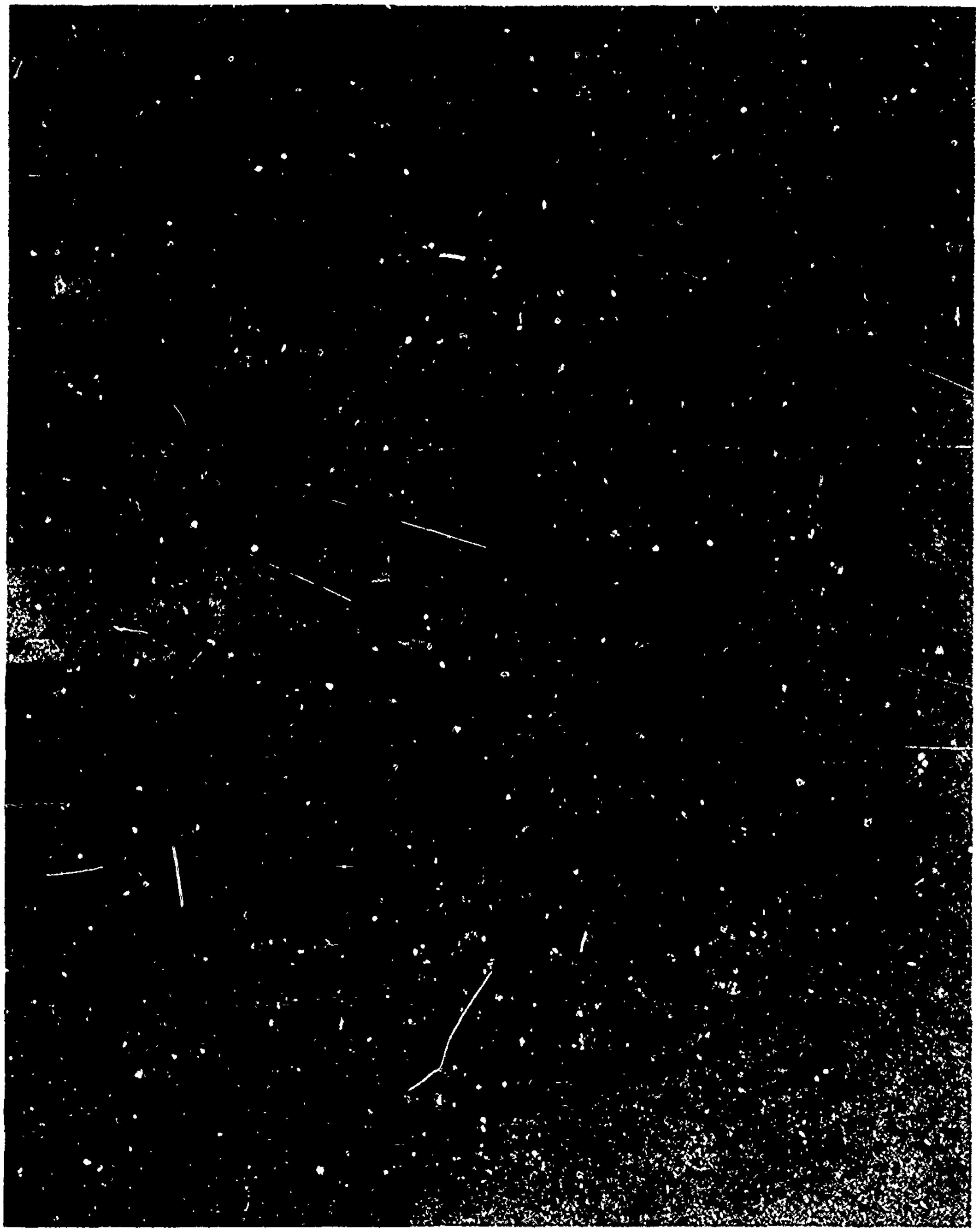

Figure 8-38. Upper Side Brace, Preparation for Final Cure

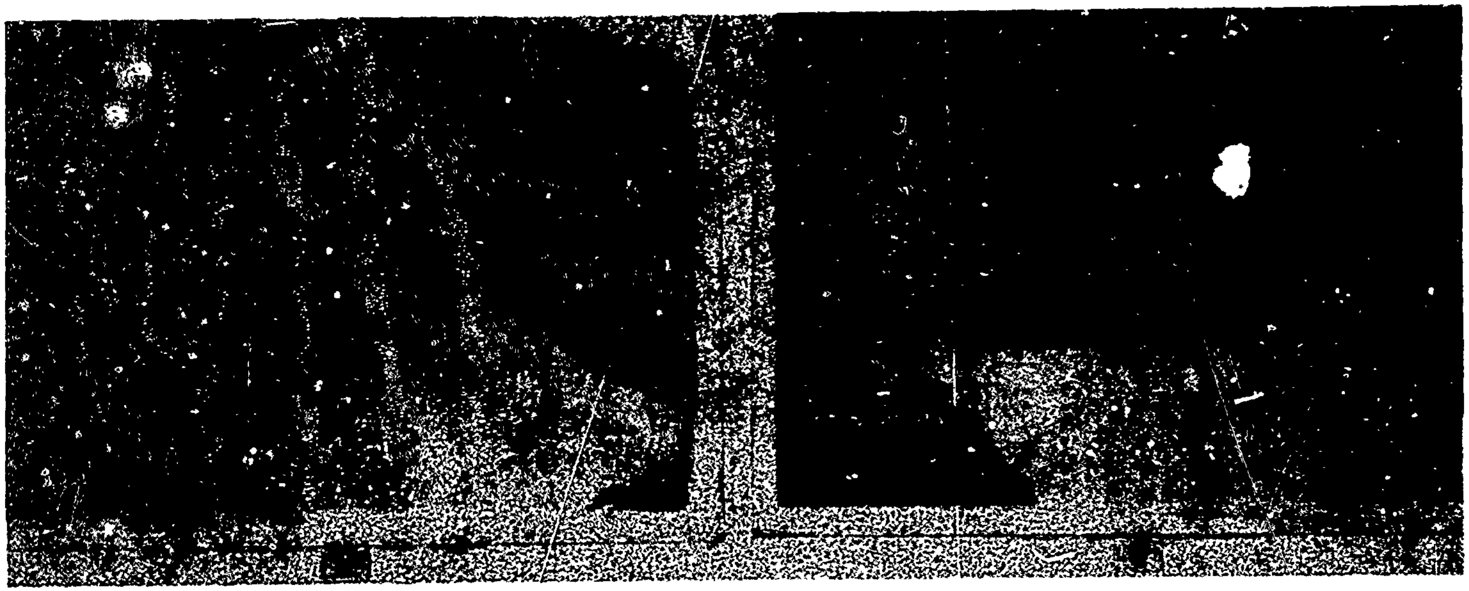

Figure 8-39. Upper Side Brace, Preparation for Final Cure

Lower Member - **This item is illustrated in Figure 8-40. The fabrication details are summarized below and the tooling illustrated in Figures 8-41 to 8-44.**

FABRICATION DETAILS - LOWER MEMBER

1. Machine honeycomb.

   a. Melt polyehtylene glycol and fill honeycomb cells.

   b. Machine honeycomb using milling machine (1.5" L x 6.945" W).

   c. Heat honeycomb to remove polyethylene glycol.

   d. Wash honeycomb with hot water.

   e. Vapor degrease.

2. Boron faceplates.

   a. Cure single ply of boron in press.

   b. Remove and cut to shape 1.5" long x 6.945" wide (2 pieces).

3. Urethane filling.

   a. Mask off center section of honeycomb starting 0.375" from each end.

   b. Fabricate nylon bag such that one face of the honeycomb is exposed.

   c. Mix the urethane.

   d. Place the urethane mixture in shallow pan.

   e. Connect vacuum pump to vacuum bag.

   f. Dip honeycomb face in urethane and let vacuum pump pull the urethane into the cells completely filling them.

   g. Let the urethane cure and disassemble.

4. Prepare for bonding.

   a. Vapor degrease honeycomb.

   b. Place FM 1000 over honeycomb assembly.

   c. Place cured facesheets on honeycomb.

5. Cure

   a. Place honeycomb assembly in pressure and cure at 350°F and 25 psi for 1 hour.

   b. Remove from press

6. Fabricate boron belt. *

   a. Place honeycomb and inserts within the boron composite.

   b. Cut two pieces boron 6.945 inches wide by 1.5 inches long.

   c. Place these pieces on the outside of boron belt over honeycomb.

7. Cure

   Same as Upper Side Brace.

8. NDT.

9. Machine part to final dimension.

10. Dimensional inspection.

11. Prepare documentation.

12. Ship.

* (The amount of boron within this assembly was 24 plies instead of the minimum 21, still maintaining the required thickness of 0.11 inch maximum).

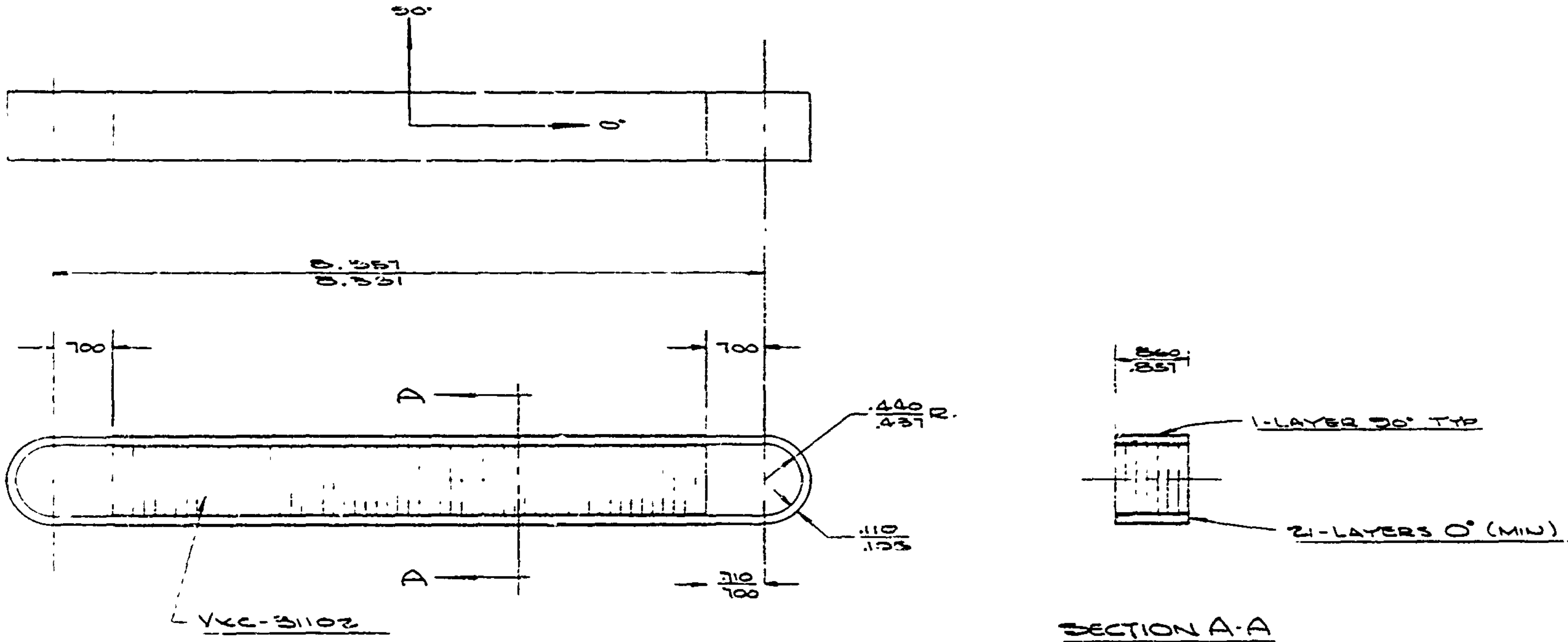

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Figure 8-40. Lower Side Brace Flange Assembly

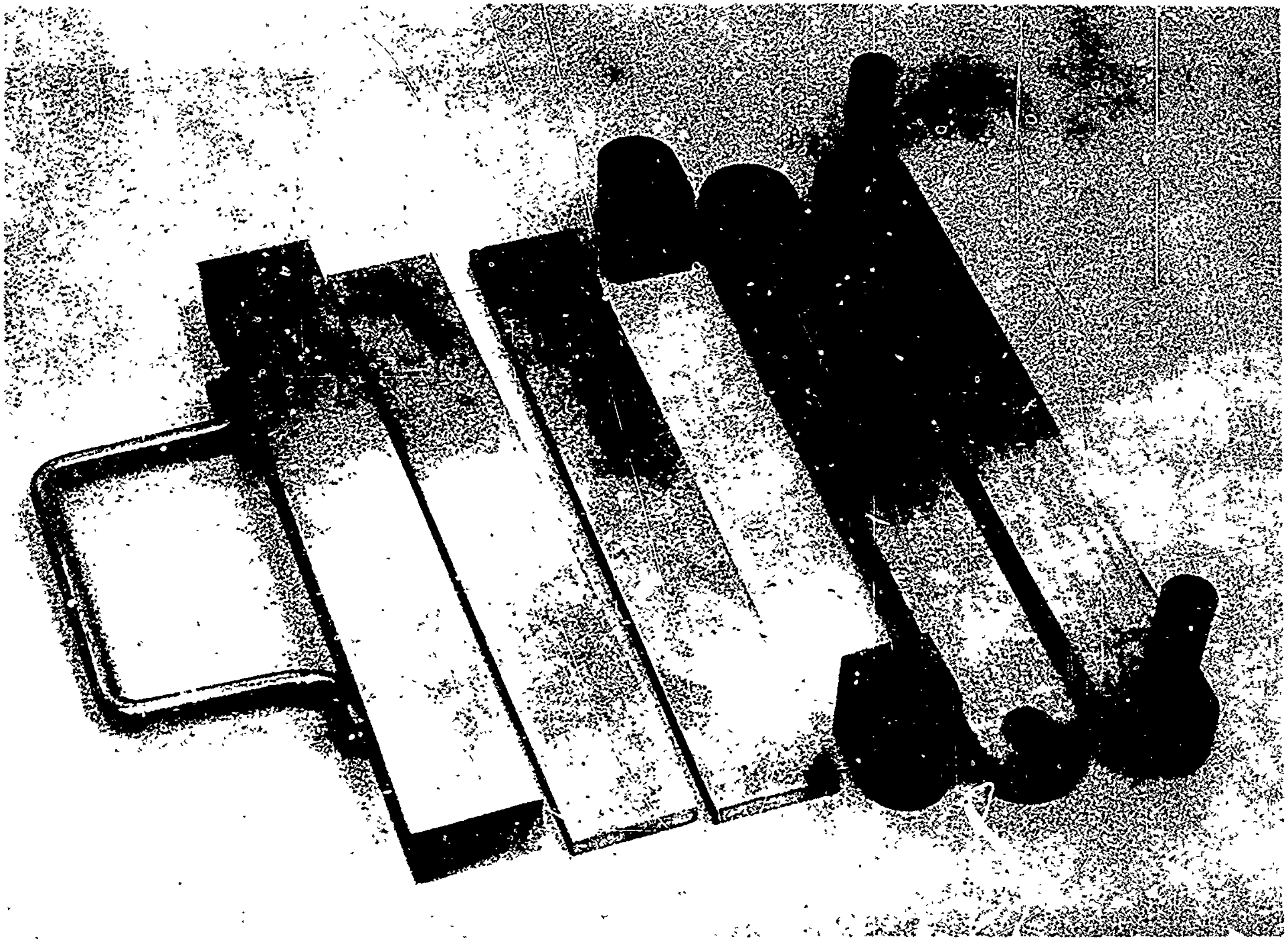

Figure 8-41. Lower Side Brace Tooling

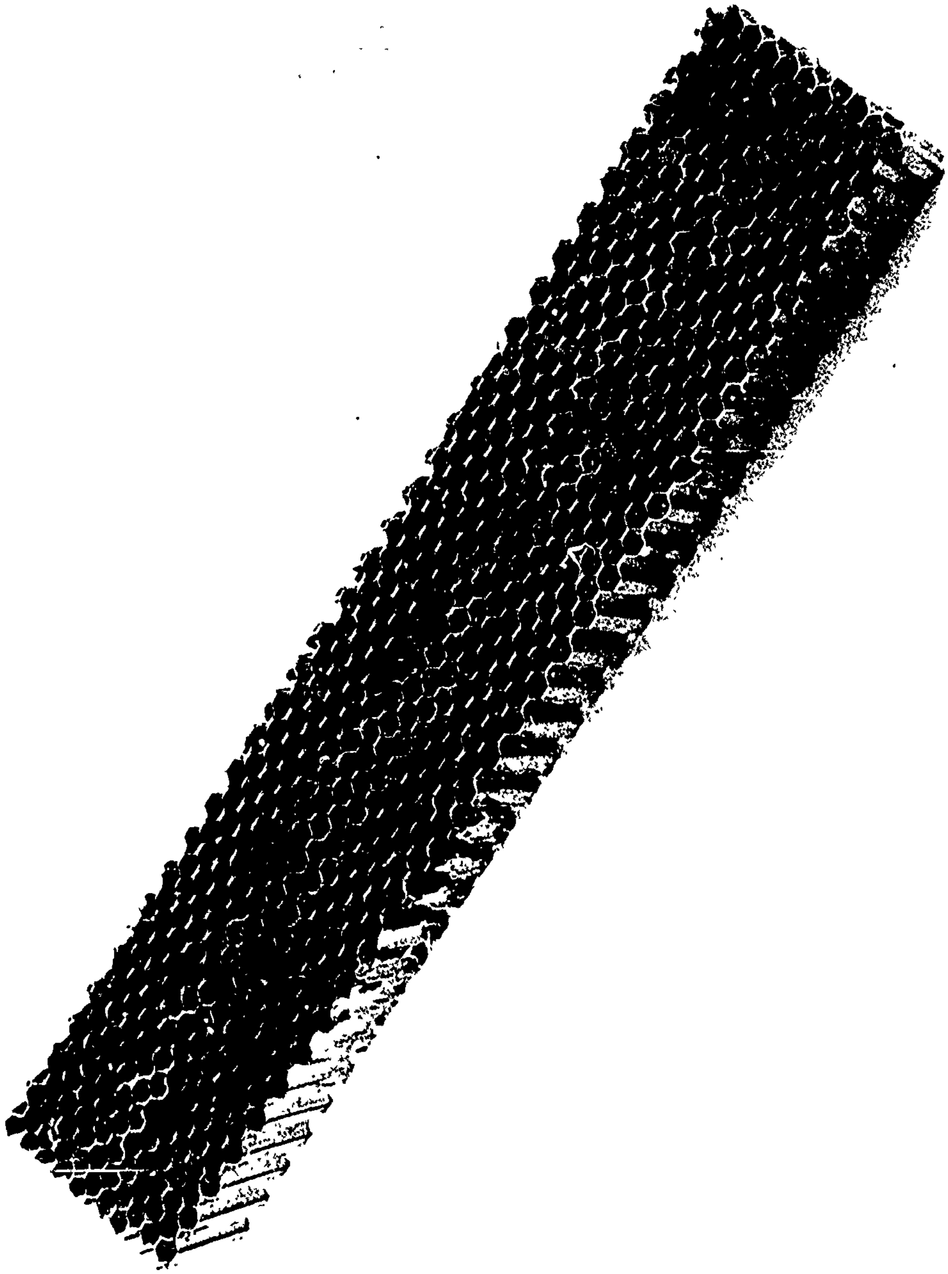

Figure 8-42. Machined Honeycomb, Lower Brace

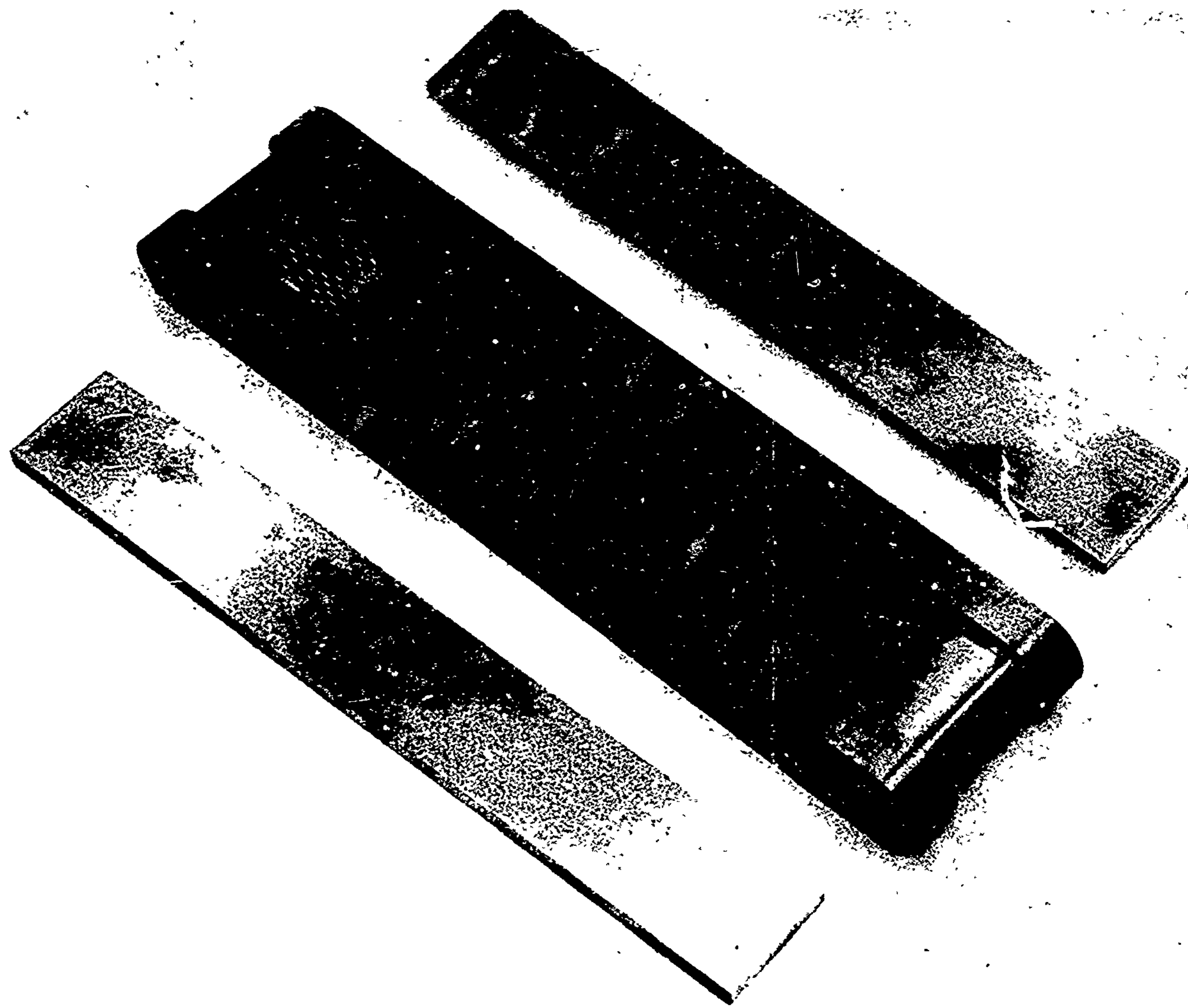

Figure 8-43. Lower Brace Tooling, Honeycomb Without Microballoons

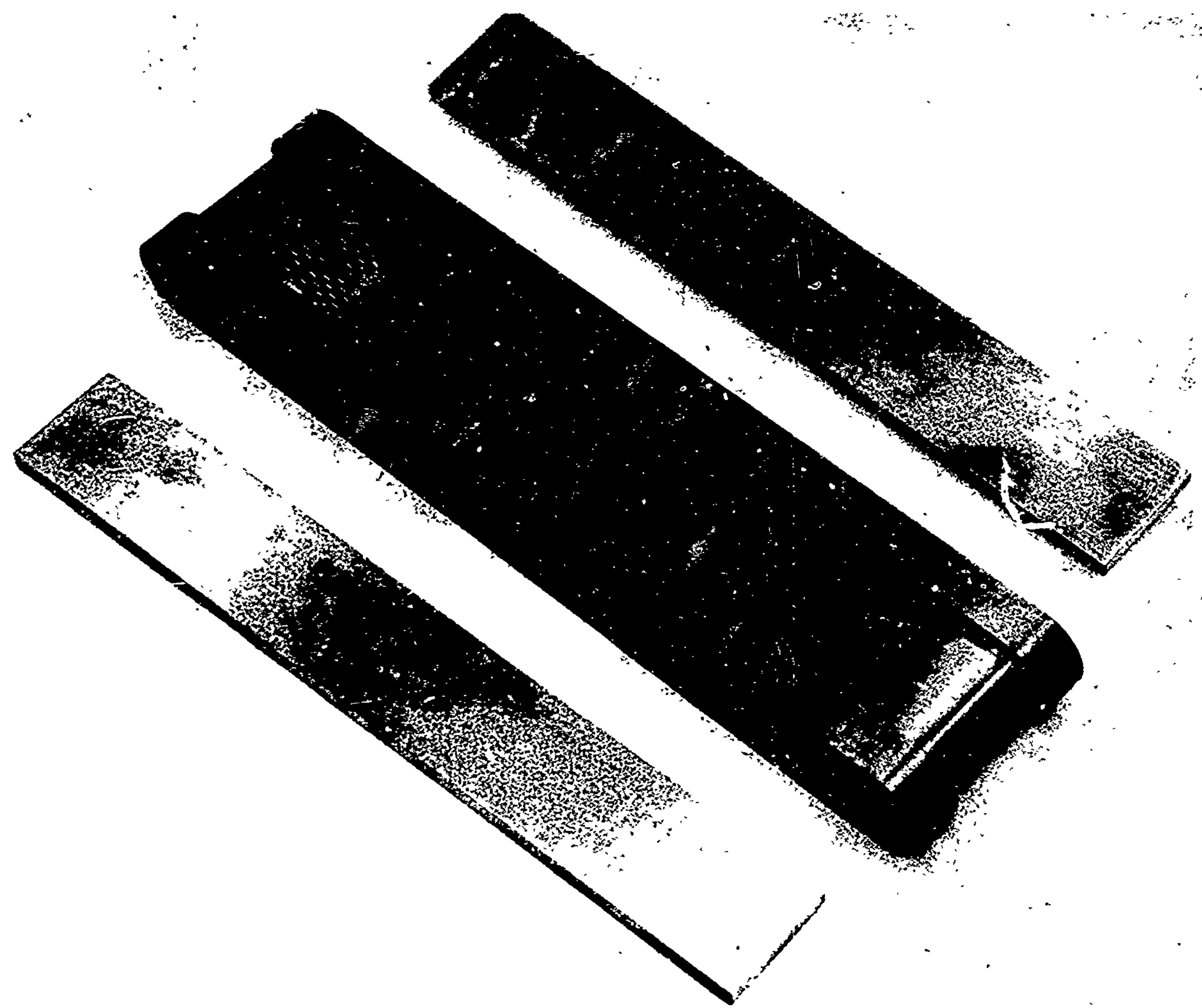

Figure 8-43. Lower Brace Tooling, Honeycomb Without Microballoons

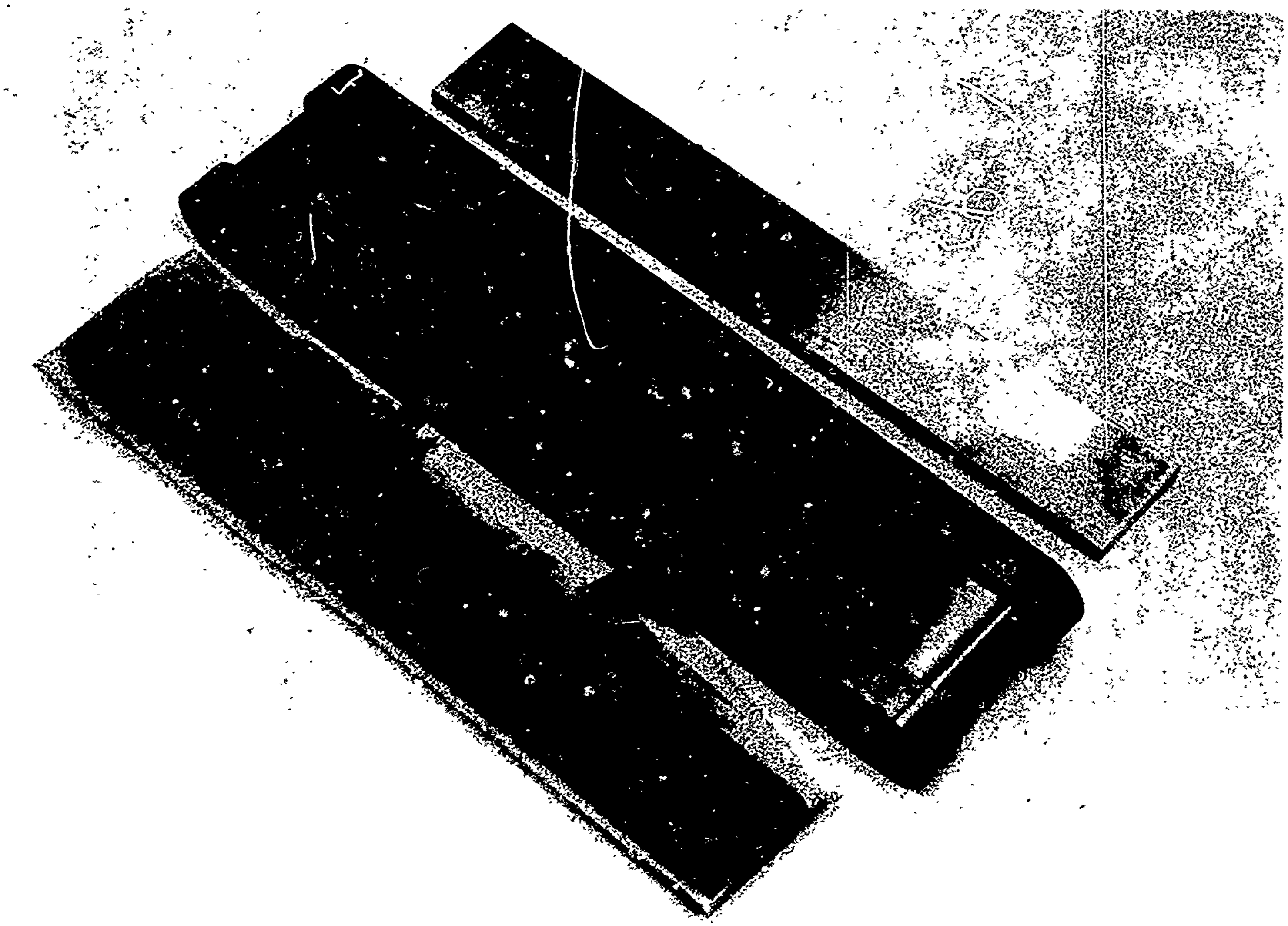

Figure 8-44. Lower Brace Tooling, Single Ply Cured Boron

2. Bendix Activity (Boron-Epoxy Side Brace Assembly) - All the miscellaneous metal fittings not included in the subassemblies shown in Figures 8-29 and 8-40 were procured or manufactured by Bendix. Some of these parts are identical to those included in the conventional side brace assemblies being fabricated and supplied by Bendix for the A-37B aircraft. The final assembly of the Hercules and Bendix supplied parts into the final assembly, Figure 5-35 were done by Bendix. This task was accomplished in the following steps:

1. Procured and inspected miscellaneous metal fittings, Figure 8-45.
2. Received and inspected Hercules furnished components (Figures 8-29 and 8-40).
3. Assembled end fittings and potted with urethane as indicated on Figures 8-46 and 8-47.
4. Reamed bushing holes to size.
5. Pressed bushings into metal end fittings.
6. Flared ends of bushings in 3 1/2 ton press.
7. Drilled bolt holes in spacer blocks, Figure 8-46.
8. Drilled 0.203 inch diameter holes, Figure 8-47.
9. Assembled all parts to form final assembly, Figure 5-35.

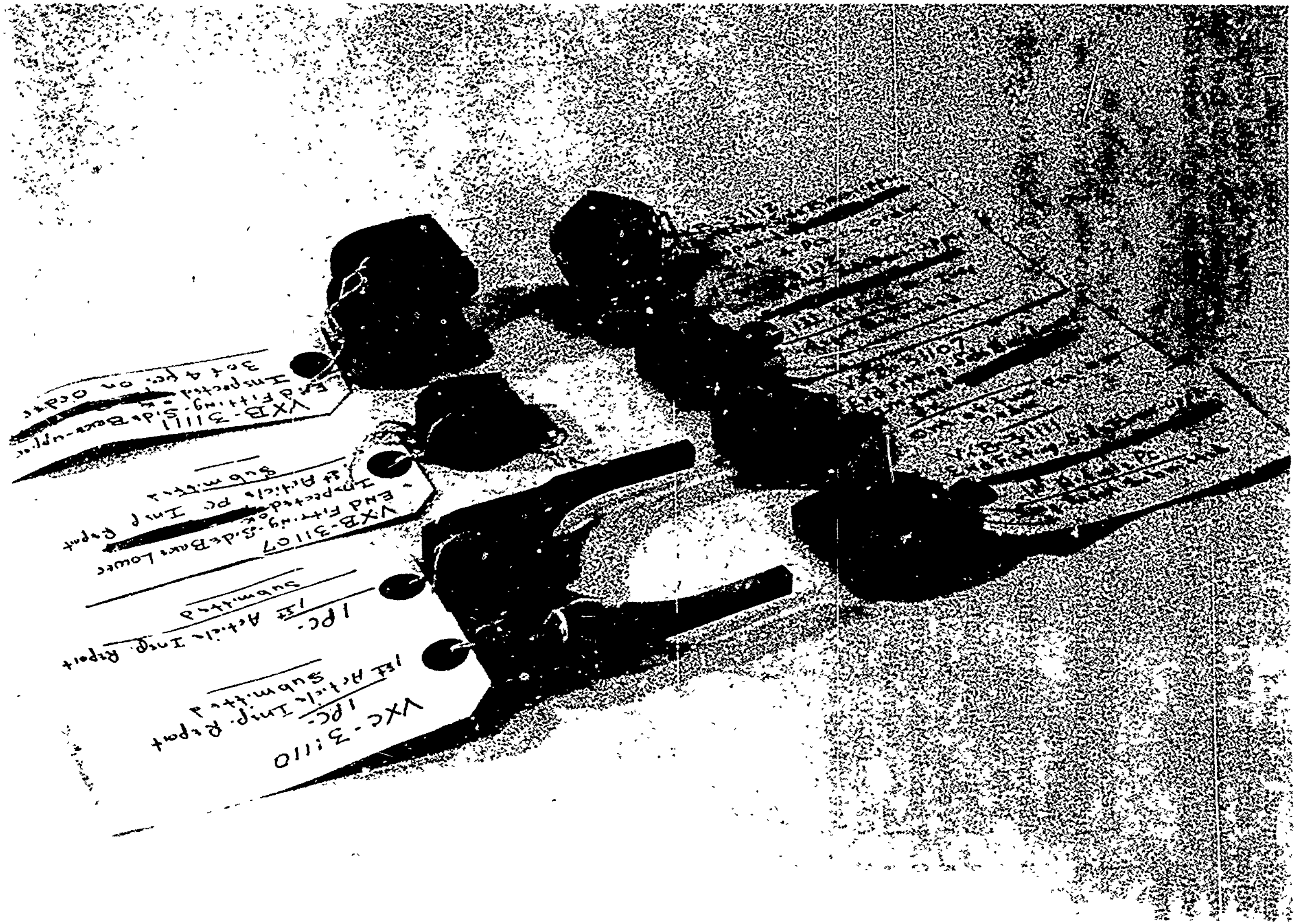

Figure 8-45. Side Brace Aluminum End Fittings

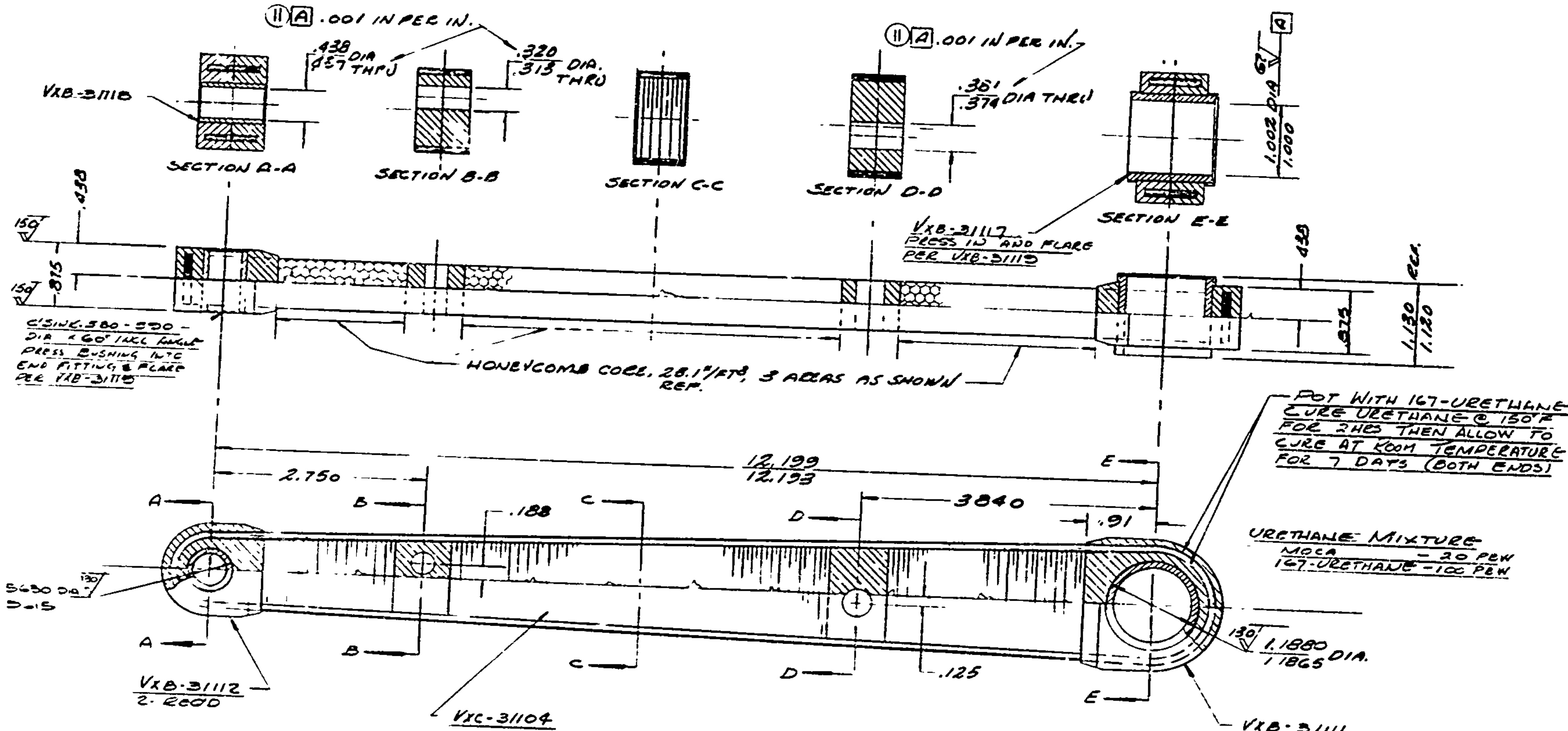

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Figure 8-46. Side Brace Upper Link

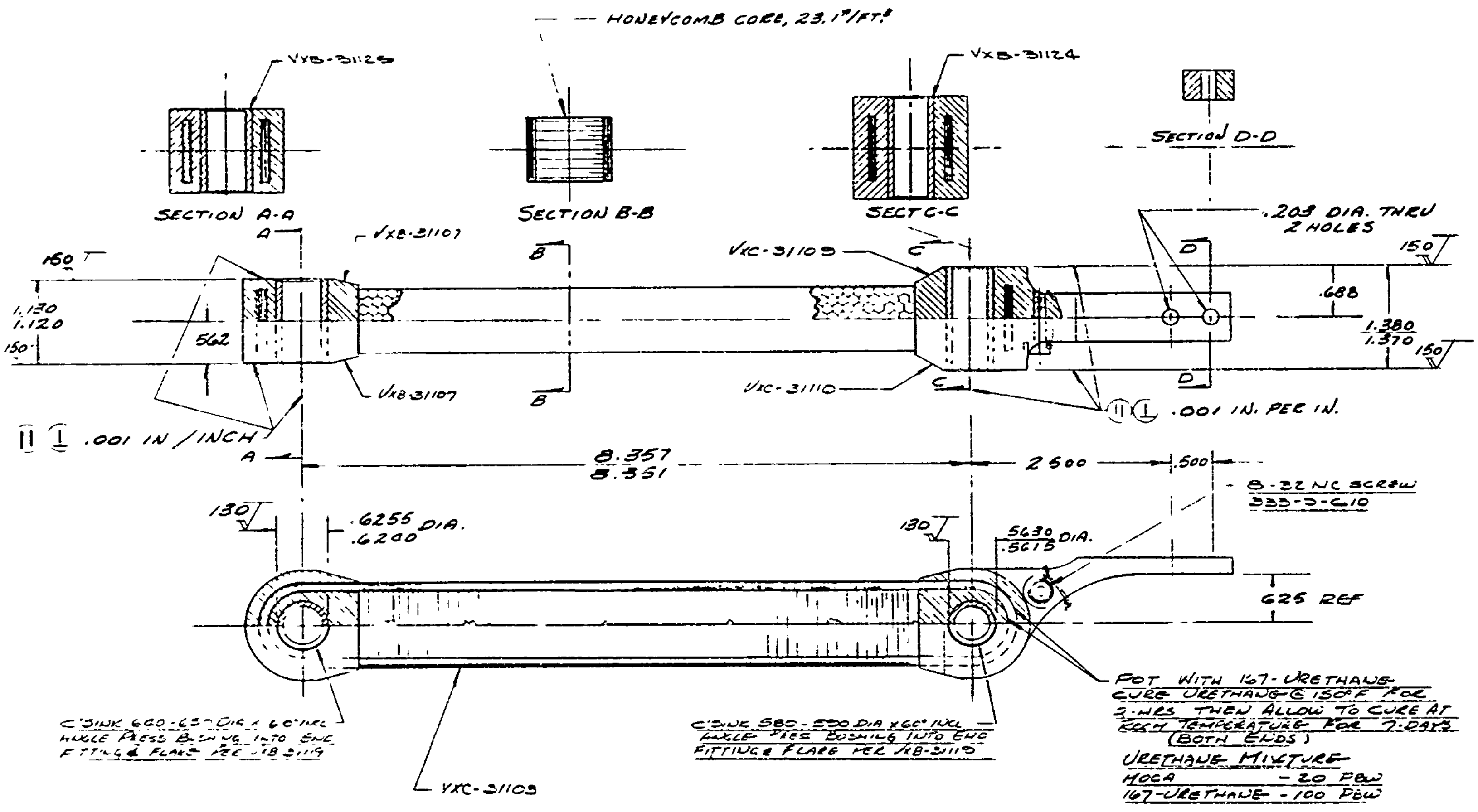

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Figure 8-47. Side Brace Lower Link

8.2.4 Fabrication of Boron-Epoxy Torque Arms

This section describes firstly by the processing applied to the actually fabricated trial specimen and secondly summarizes the processing intended for the finally proposed torque arm.

8.2.4.1 First Design - Trial Specimen

This component is illustrated in detail in Figure 5-46.

The torque arm is composed of four boron-epoxy segments, two graphite epoxy overwraps and one steel insert. The side rails, or flanges, are constructed from broad goods with spiral doilies at the lug ends. The straight side rail is fabricated the same as the pin bearing specimens, Paragraph 8.2.2. The other side rail has two offsets and a special fixture, Figures 8-48 and 8-49, was required to process this part. As detailed below, consolidation was required after every sequence of 6 to 10 layers of broad goods in order to keep the material in alignment.

The side plates are ±45° segments. These were fabricated as 0°, 90° flat plates and cut to provide the desired shapes.

FM 1000 was used as the bonding material to complete the assembly. Graphite tape was applied at two locations to form the reinforcement bands.

This component was fabricated entirely by Hercules, except that the three lug holes were drilled and bushings applied by Bendix.

Following is the detailed process by which the torque arm was fabricated.

TORQUE LINK FABRICATION PROCESS

Materials:

- Graphite HTS Broadgoods (2002T)
- Silicone Rubber Sheet - 1/8" thick MIL-R-5847 Class 2
- Boron BP 907 Broadgoods (2002B)
- Wafers (Spiral Doilies 2" diameter, 2 plies thick) see attached procedure
- Teflon Coated Glass Scrim (TX 1040) Pallflex Products Corporation, Kennedy Drive, Putnam, Conn.
- Teflon Coated Glass Cloth (Armalon 95-604) E. I. duPont, Industrial Fabric Sales, Wilmington, Del.
- Boron Filaments - Hamilton Standard
- High Strength Adhesive (FM 1000 -.050 $\pm$.005 lbs/ft^2) American Cyanamid Company
- Sheet Resin (BP 907-104A - 0.020 lb/ft^2) - American Cyanamid Company
- Liquid Resin (BP 907) - American Cyanamid Company
- Mold Release (Frekote 33) - Frekote Inc., 2300 N. Emerson Avenue, Indianapolis, Ind.
- Vacuum Bag (0.002" Nylon Film)

Straight Side Rail Fabrication (0.560" thick)

Preparation: Use mold design previously used for bearing test specimen fabrication. Clean and apply mold release.

Cut broadgoods into the following sizes:

50 pieces 2" wide by 7.530" long

66 pieces 2" wide by 7.250" long

The short pieces were used in connection with the wafers or spiral doilies. A curvature was cut in these pieces and also the exact length was cut in the same operation by using a special die cutter. Photo sequence Figures 8-50, -51 and -52 show how this cutter was used and the effects of the cutter.

Layup and Compaction

A piece of sheet resin (BP 907-104A) 2" wide by 7.53" long was placed in the bottom of the mold. Layup sequence was as follows:

1. 2 plies long
2. 2 plies short + 1 wafer
3. 1 ply long
4. 2 plies short + 1 wafer
5. 1 ply long

Upon completion of this layup sequence, the part was compacted. Compaction steps are as follows:

a. Cut three pieces Armalon 95-604 to 2" wide by 7.53" long.

b. Layup Armalon over part in mold

c. Place top of mold over Armalon

d. Fabricate vacuum bag around mold

e. Place mold in heated platen press at 180°F and 100 psi on mold for 1/2 hour

f. Cool mold while maintaining pressure

g. Remove from press and disassemble

h. Discard Armalon

After compaction, layup continued as follows:

6. 2 plies short + 1 wafer
7. 2 plies long
8. 2 plies short + 1 wafer
9. 1 ply long

Compaction steps are repeated (a through h) and layup continued.

10. 2 plies short + 1 wafer
11. 1 ply long
12. 2 plies short + 1 wafer
13. 2 plies long
14. 2 plies short + 1 wafer
15. 1 ply long

Compaction steps are repeated (a through h) and layup continued.

16. 2 plies short + 1 wafer
17. 2 plies long
18. 2 plies short + 1 wafer
19. 2 plies long
20. 2 plies short + 1 wafer
21. 1 ply long

Compaction steps are repeated (a through h) and layup continued.

22. 2 plies short + 1 wafer
23. 1 ply long
24. 2 plies short + 1 wafer
25. 2 plies long
26. 2 plies short + 1 wafer
27. 1 ply long
28. 2 plies short + 1 wafer
29. 1 ply long

Compaction steps are repeated (a through h) and layup continued.

30. 2 plies short + 1 wafer

31. 2 plies long

32. 2 plies short + 1 wafer

33. 1 ply long

Compaction steps are repeated (a through h) and layup continued.

34. 2 plies short + 1 wafer

35. 2 plies long

36. 2 plies short + 1 wafer

37. 2 plies long

Compaction steps are repeated (a through h) and layup continued.

38. 2 plies short + 1 wafer

39. 1 ply long

40. 2 plies short + 1 wafer

41. 1 ply long

42. 2 plies short + 1 wafer

43. 2 plies long

Compaction steps are repeated (a through h) and layup continued.

44. 2 plies short + 1 wafer

45. 1 ply long

46. 2 plies short + 1 wafer

47. 1 ply long

Compaction steps are repeated (a through h) and layup continued.

48. 2 plies short + 1 wafer

49. 2 plies long

50. 2 plies short + 1 wafer

51. 1 ply long

Compaction steps are repeated (a through h) and layup continued.

52. 2 plies short + 1 wafer

53. 2 plies long

54. 2 plies short + 1 wafer

55. 2 plies long

Compaction steps are repeated (a through h) and layup continued.

56. 2 plies short + 1 wafer

57. 1 ply long

58. 2 plies short + 1 wafer

59. 1 ply long

Compaction steps are repeated (a through h) and layup continued.

60. 2 plies short + 1 wafer

61. 2 plies long

62. 2 plies short + 1 wafer

63. 1 ply long

Compaction steps are repeated (a through h) and layup continued.

64. 2 plies short + 1 wafer

65. 1 ply long

66. 2 plies short + 1 wafer

67. 2 plies long

Compaction steps are repeated (a through h).

Cure: Install one piece of sheet resin (BP 907) 2" wide by 7.53" long to the top ply of layup.

Cut two pieces TX 1040 Teflon coated glass and three pieces Armalon. Sizes should be 2" wide by 7.53" long. Apply these pieces with the TX-1040 next to the layup.

Install top of mold and place a thermocouple in the mold. Vacuum bag the assembly and place in press. Cure cycle is as follows:

1/2 hour at 180°F

1/2 hour at 280°F

1 hour at 350°F

Vacuum and 100 psi pressure are applied throughout the cure cycle. Cool part while maintaining pressure. Remove assembly from press and disassemble.

Machining: Machining is accomplished with 180 grit diamond wheel running at approximately 2000 ft/min and water coolant. Machined straight side rail is shown in Figure 8-53. Metal insert is shown in Figure 8-54. Figure 8-55 shows metal insert and composite together.

CURVED SIDE RAIL FABRICATION (0.395")

Preparation

Use mold fabricated per drawing 60000M10008.

Clean and apply mold release.

Cut broadgoods into the following sizes:

33 Pieces - 2" wide by 8.23"
46 Pieces - 2" wide by 7.8"

As in the straight side rail, the short pieces were used in connection with the spiral wafers and were cut using the special die cutter.

Layup and Compaction

A sheet of resin (BP907-104A) was cut to 2" by 8.23" and placed in the lower part of the mold. Broadgoods were then layed up as follows:

1. 2 plies long
2. 2 plies short + 1 wafer
3. 1 ply long
4. 2 plies short + 1 wafer
5. 1 ply long
6. 2 plies short + 1 wafer

Upon completion of this layup sequence, the part was compacted. Compaction steps are as follows:

a. Cut three pieces of Armalon 95-604 to 2" wide by 8.23" long.

b. Lay up Armalon over part in mold.

c. Cut three pieces of silicone rubber sheet to 2" wide by 8.23" long.

d. Lay up as many pieces of rubber sheet as needed to achieve minimum 0.4" thickness between composite, Armalon and rubber.

e. Place top on mold and apply a vacuum bag (nylon) over the assembly.

f. Install mold in press with heated platens.

g. Apply 180°F and 100 psi pressure for ½ hour.

h. Cool press while maintaining pressure.

i. Disassemble mold and remove Armalon.

j. Discard Armalon.

After compaction, lay up continued as follows:

7. 2 plies long
8. 2 plies short + 1 wafer
9. 1 ply long
10. 2 plies short + 1 wafer
11. 1 ply long
12. 2 plies short + 1 wafer
13. 1 ply long

Compaction steps are repeated (a through j) and layup continued:

14. 1 ply long
15. 2 plies short + 1 wafer
16. 1 ply long
17. 2 plies short + 1 wafer
18. 1 ply long

Compaction steps are repeated (a through j) and layup continued:

19. 2 plies short + 1 wafer
20. 2 plies long
21. 2 plies short + 1 wafer
22. 1 ply long

Compaction steps are repeated (a through j) and layup continued:

23. 2 plies short + 1 wafer
24. 1 ply long
25. 2 plies short + 1 wafer
26. 2 plies long
27. 2 plies short + 1 wafer
28. 1 ply long

Compaction steps are repeated (a through j) and layup continued:

29. 2 plies short + 1 wafer
30. 1 ply long
31. 2 plies short + 1 wafer
32. 2 plies long
33. 2 plies short + 1 wafer
34. 1 ply long

Compaction steps are repeated (a through j) and layup continued:

35. 2 plies short + 1 wafer
36. 1 ply long
37. 2 plies short + 1 wafer
38. 2 plies long

Compaction steps are repeated (a through j) and layup continued:

39. 2 plies short + 1 wafer
40. 1 ply long
41. 2 plies short + 1 wafer
42. 1 ply long
43. 2 plies short + 1 wafer
44. 1 ply long

Compaction steps are repeated (a through j) and layup continued:

45. 1 ply long
46. 2 plies short + 1 wafer
47. 1 ply long
48. 2 plies short + 1 wafer
49. 2 plies long

Cure

Compaction steps are repeated (a through j). Sheet of BP907-104A resin cut to 2" by 8.23" is applied to the layup. Two pieces of teflon coated scrim (TX-1040) and three pieces of Armalon are cut to the above size and installed over resin with the TX-1040 against the resin. The assembly of the mold is completed with the addition of the top and a thermocouple. A nylon vacuum bag is installed and the entire assembly placed in a heated platen press. The cure conditions are as follows:

½ hour at 180°F
½ hour at 280°F
1 hour at 350°F

A vacuum and a pressure of 100 psi maintained throughout the cure. Cooldown is also accomplished with pressure and vacuum. The mold is disassembled and the part removed.

Machining

Machining was accomplished in a similar manner to the techniques used in the straight side rail. Figures 8-48 and -49 show surved rail tooling with scrap ends of side rail in place. Figure 8-56 shows straight rail and curved rail scrap together.

SIDE PLATE FABRICATION

Preparation

Use a 7" x 13" flat plate mold.

Clean and apply mold release.

Cut the broadgoods into the following sizes:

3 Pieces - 7" wide by 13" long "A"
3 Pieces - 13" wide by 7" long "B"

Layup and Compaction

Layup sequence to be alternate plies of cut broadgoods A,B,A,B,A,B.

Upon completion of layup sequence, the part was compacted as follows:

a. Cut three pieces Armalon (95-604) to 7" wide by 13" long.

b. Lay up Armalon over broadgoods.

c. Place top on mold.

d. Fabricate vacuum bag around mold.

e. Place mold in heated platen press at 180°F and 100 psi for ½ hour.

f. Cool mold while maintaining pressure.

g. Remove from press and disassemble.

h. Discard Armalon.

Cure

a. Cut two pieces teflon coated glass scrim (TX-1040) to 7" x 13".

b. Cut one piece Armalon.

c. Place TX-1040 over composite and Armalon on top.

d. Place mold top over Armalon.

e. Fabricate nylon vacuum bag and place over assembly.

f. Place assembly in heated platen press and cure as follows with vacuum and 100 psi pressure:

½ hour at 180°F
½ hour at 280°F
1 hour at 350°F

g. Cooldown under pressure.

h. Disassemble.

i. Remove part.

Machining

Machining was accomplished utilizing standard technique with diamond wheel. Configuration was per print.

TORQUE LINK

(Assembly)

Steel insert was trial fitted to grooves in side rails with FM-1000 before degreasing.

Parts were degreased using Metal Cleaning procedure (vapor degreasing).

Primer was used on both the side rail and steel insert.

FM-1000 applied as in trial fit and side rails assembled.

Parts of mold used to cure part in press.

Cured to FM-1000 procedure cure.

Removed from press and disassembled.

Side panels assembled using FM-1000 and using same cure cycle.

Side panels machined to edge of side rails.

Two bands of graphite tape wrapped to desired thickness as shown on print.

Tape cured in autoclave using internal tooling and vacuum bag. Dams were fabricated using pieces of rubber.

The complete torque link is shown in Figures 5-47 and -48.

METAL CLEANING PROCEDURE

4130 Steel
4340

1. Clean surface with Scotch Brite.
2. Wash metal in warm water detergent; 1 tablespoon to 1 pint water.
3. Degrease with MEK.
4. Wipe surface with clean cloth and alcohol until no discoloration of cloth is present.
5. Place metal in vapor degreaser (triclean) for 15 minutes.
6. Try water break test with distilled water.
7. After successful water break test, repeat Steps 4 and 5.
8. Dry in 150° oven for ½ hour and immediately apply primer to metal surface.

FM-1000 EP-15 CURE SCHEDULE

1. One (1) hour heatup to 340° ± 10°F.
2. Cure 1 hour at 350°F.
3. Cool down in oven prior to removing weight from part.

FM-1009 - 8 Primer

1. Thin coat.
2. Air dry 30 minutes at room temperature.

DOUBLE PLY BORON WAFER WINDING

Mandrel

A winding mandrel was fabricated for this process. Two inches in diameter with a 3/4" shank to chuck on in lathe. Front end of mandrel had a .010 step on face, 5/8" in diameter. A shaft extended from center of 5/8" diameter with 1/4" -20 threads. A 2" disc, ½" thick was fitted over 1/4" shaft up against 5/8" diameter, leaving a .010" groove.

Winding

Freekote mandrel. End disc was covered with .001" thick teflon film.

Two spools of boron placed about 8 feet from lathe. Boron was threaded through a glass tube with two rubber ends to hold the resin.

Liquid BP-907 resin used. 50% solids.

A guide was placed on compound of lathe even with or slightly above the 5/8" diameter.

Boron ends after passing through rubber ends of glass tube are attached to mandrel at 5/8" diameter in groove with Duco cement. End cap installed, nut tightened and mandrel chucked in lathe, threading boron wire through guide.

Lathe chuck was rotated at approximately 30 RPM.

Guide was adjusted as diameter increased.

At conclusion of winding, a heat gun was used to heat mandrel for "B" staging (approximately 180°) for ½ hour.

Mandrel removed from lathe and placed in dry ice until frosty. Nut loosened and end cap removed. Boron wafer loosened from mandrel with knife blade.

A piece of BP-907 Resin Paper is immediately applied to one side of wafer, leaving release paper on one side. A narrow strip of green tape is applied to other side. Part is sealed in nylon and stored in freezer until used.

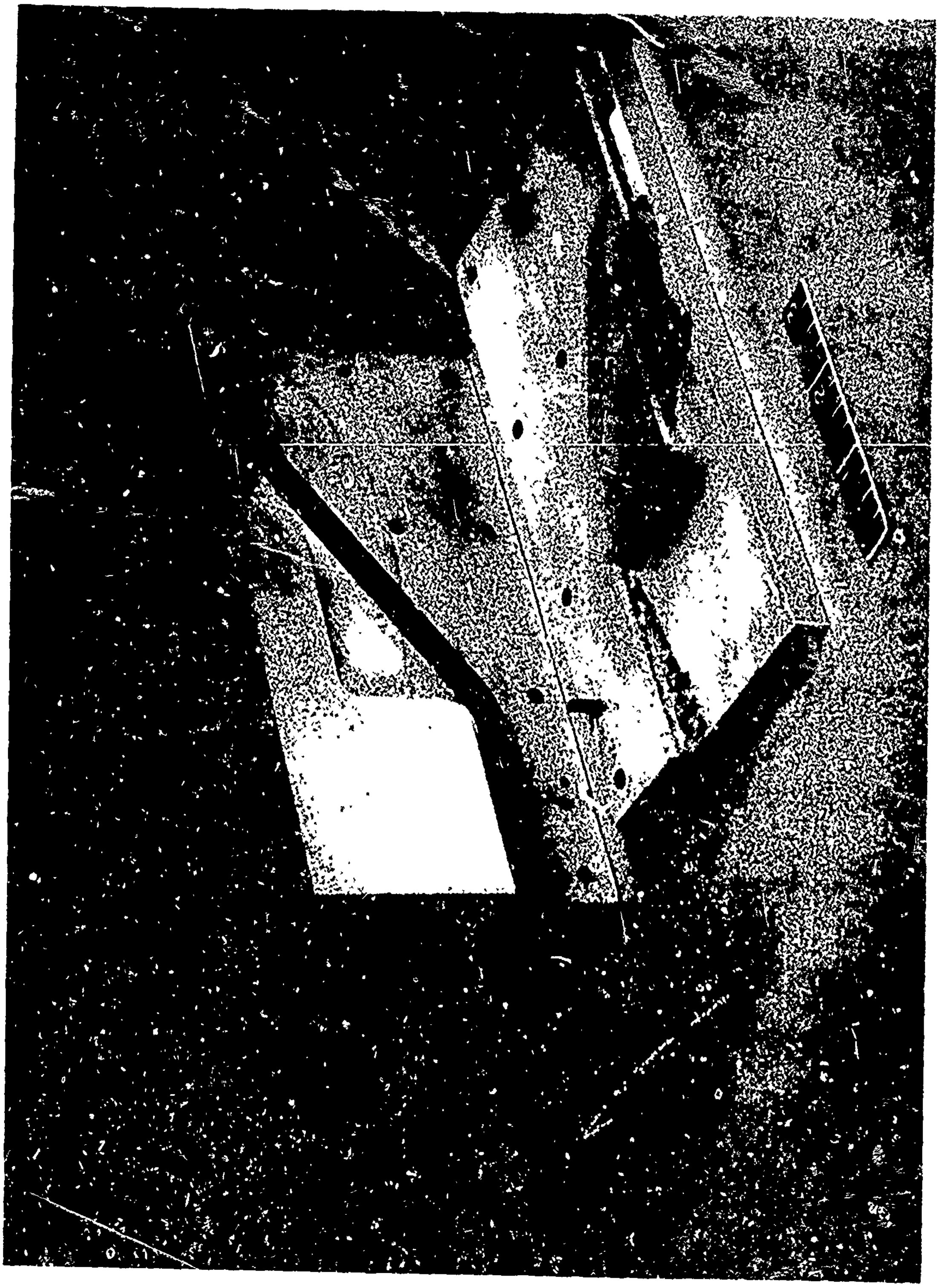


Figure 8-48. Curved Side Rail Tooling

Figure 8-49. Rail Tooling with Curved Rail Scrap Together

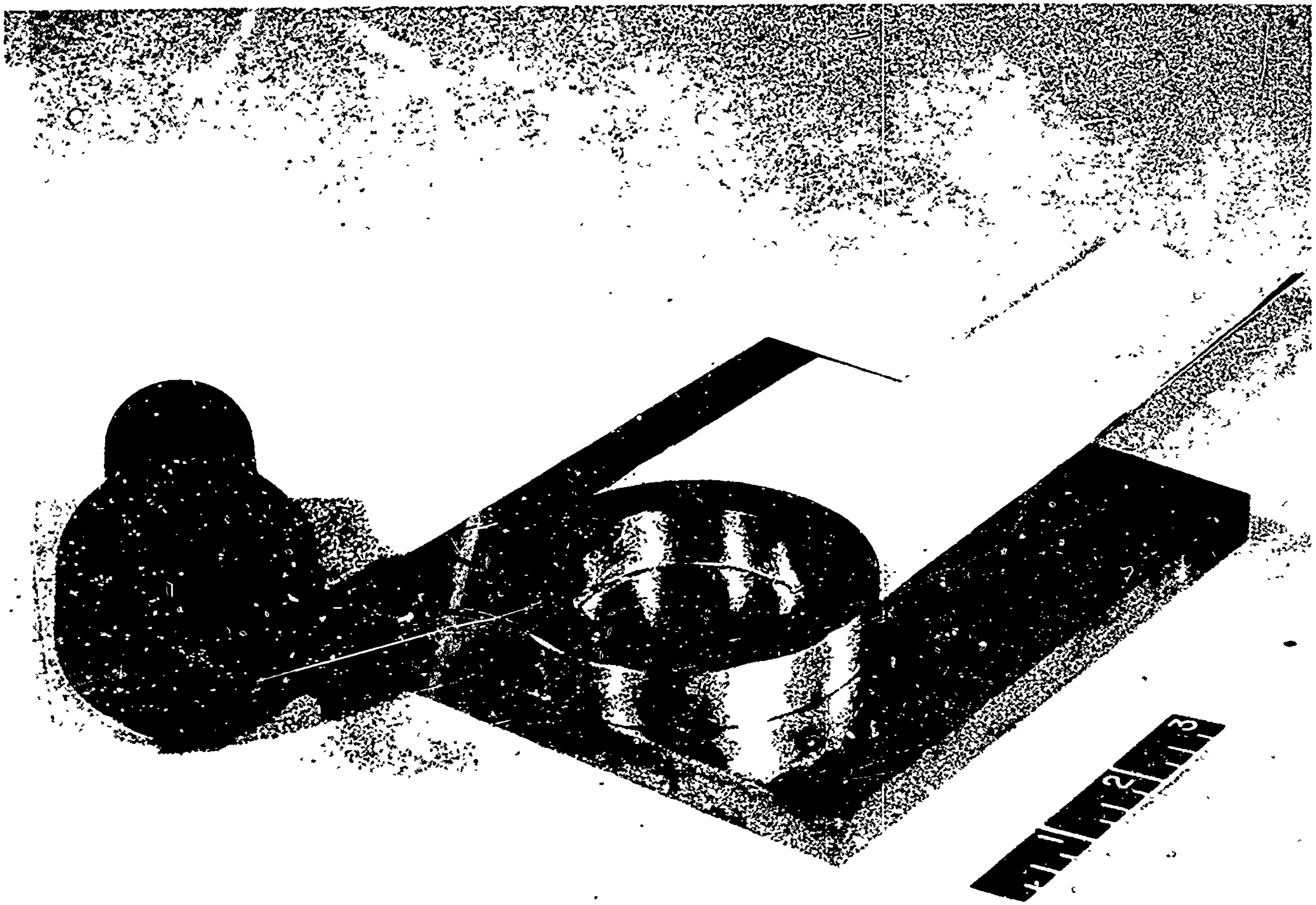


Figure 8-50. Special Die Cutter

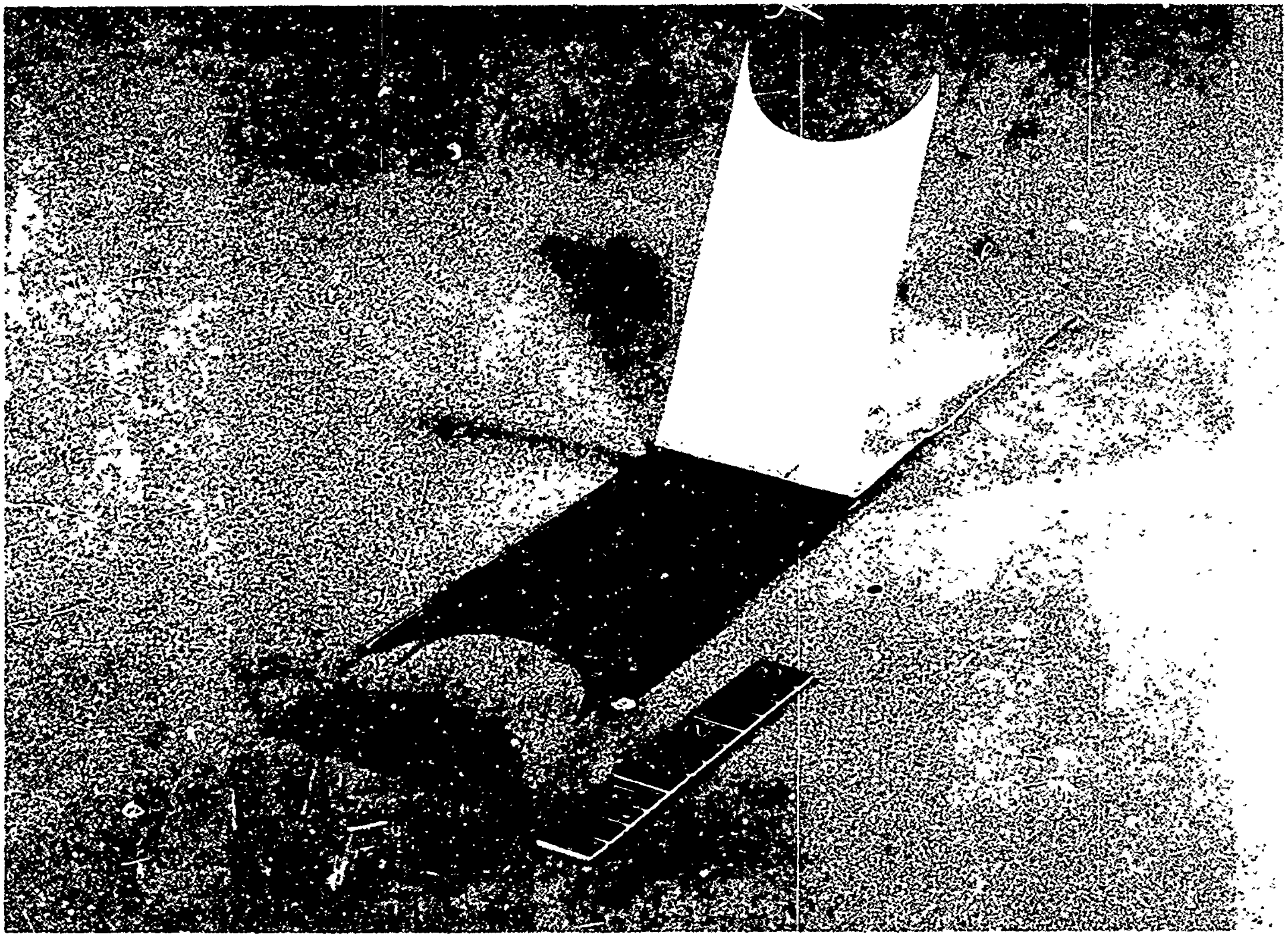


Figure 8-52. Boron/Epoxy Broad Goods - After Cutting

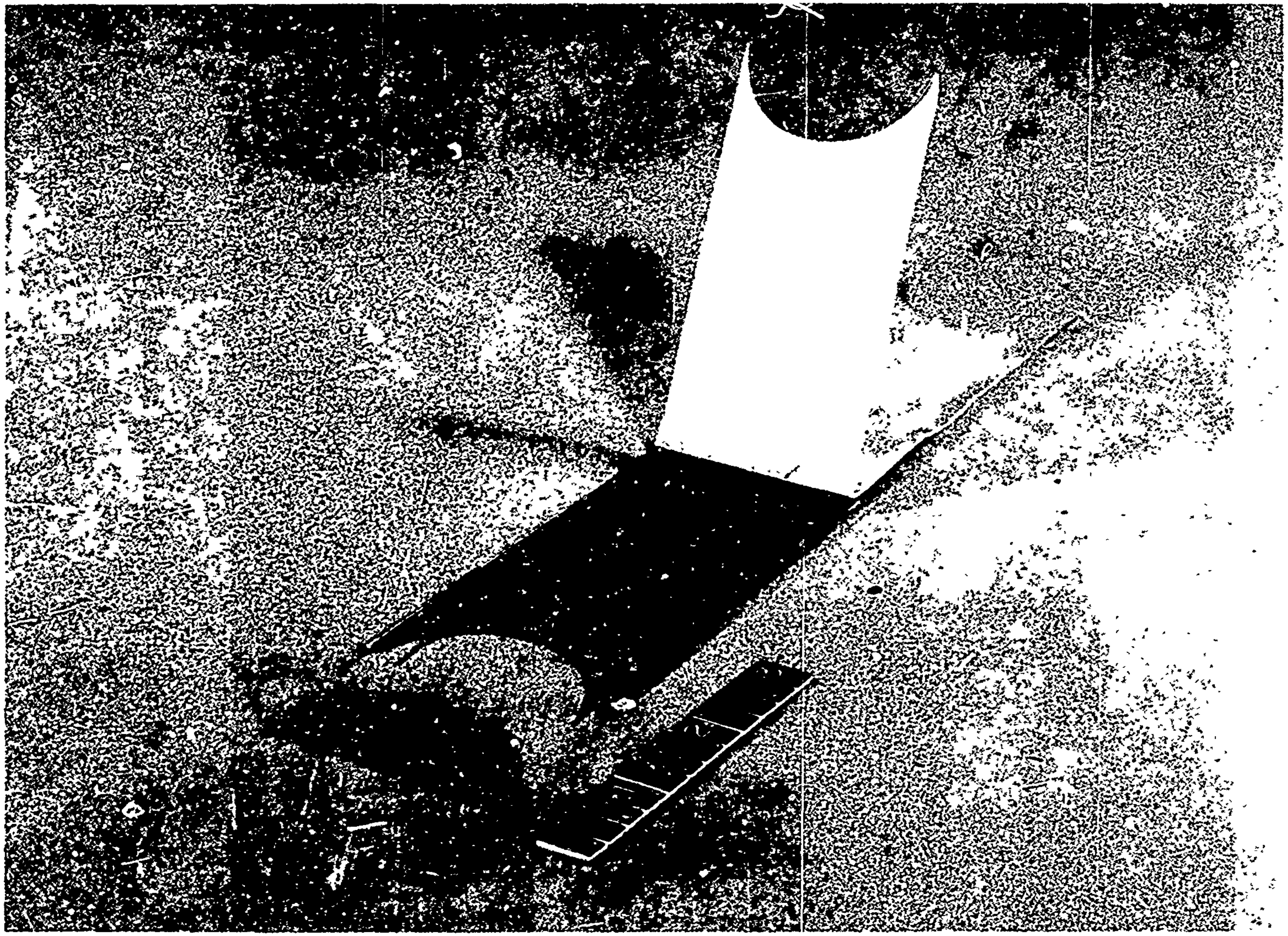


Figure 8-52. Boron/Epoxy Broad Goods - After Cutting

Figure 8-53. Machined Straight Side Rail

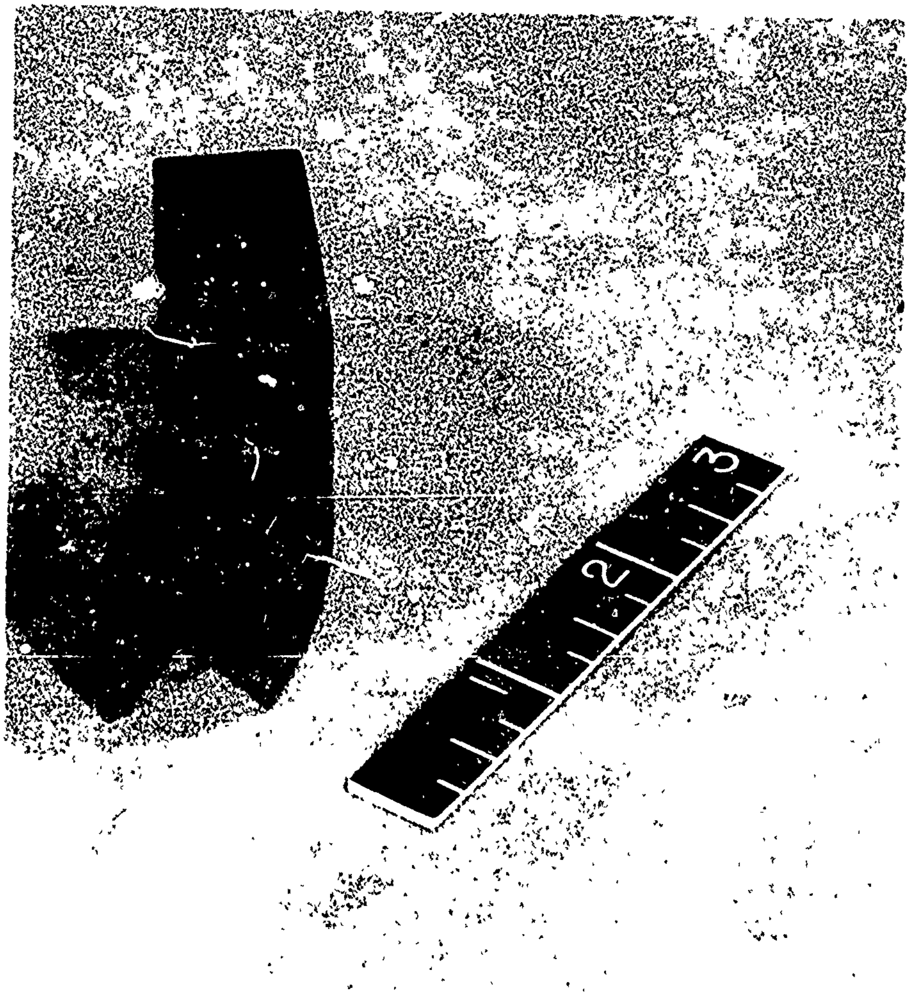


Figure 8-54. Metal Insert - Knee Lug

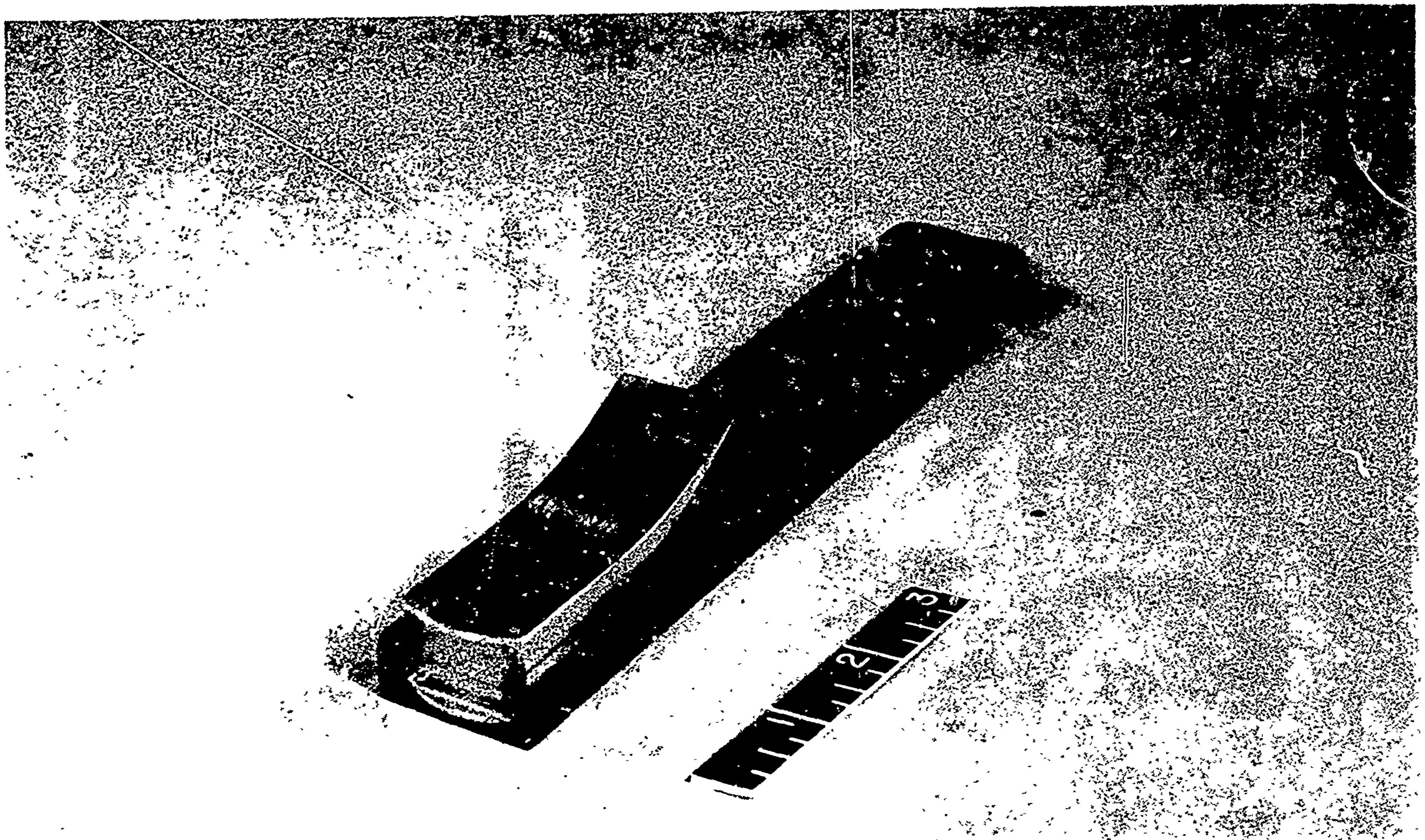


Figure 8-55 Metal Insert and Straight Side Rail

Figure 8-56. Straight Rail with Curved Rail Scrap

8.2.4.2 Second Design - Finally Proposed Concept

The torque arm assembly would be fabricated in two steps. First Hercules would fabricate and supply the subassembly shown in Figure 5-46. This item, along with various metallic fittings to be procured by Bendix, will be assembled by Bendix into the complete assembly shown in Figure 6-4.

1. Hercules Activity - This design is very similar to the trial specimen for which the processing details are given in Paragraph 8.2.4.1. Therefore, most of the processing details are given in paragraph 8.2.4.1. Therefore, most of the processing steps would be identical. The knee end of the revised torque arm, however, would require some new processing steps.

The shear plates used at the knee end would be fabricated, partially cured and inserted in the fixture prior to laying in the flange material. The knee end of the flange laminae would have the slots stamped out prior to insertion in the fixture. The laminae would require consolidation a number of times to compact the structure and hold the composite in place during fabrication.

2. Bendix Activity - Bendix would receive from Hercules the torque arm assembly shown in Figure 5-46 except that the lugs holes would not be drilled nor the bushings pressed in as shown. Bendix would then complete fabrication and assembly according to the following steps:

1. Drill lug holes in boron-epoxy lugs using procedure outlined in Paragraph 7.2.2.
2. Press in bushings.
3. Procure remaining metallic fittings.
4. Assemble into final assembly shown in Figure 6-4.

8.2.5 Fabrication of Boron-Epoxy Outer Cylinder Products

This section describes firstly the processing involved in the Phase I trial specimens and secondly the processing applied to the fabrication of the Phase II prototype clyinder.

8.2.5.1 Trial Specimens

These specimens are illustrated in the previous discussion on design, Paragraph 5.3.1.3.

Three tubular specimens were fabricated during the Phase I effort. These tubes had wall thicknesses of 10, 48, and 32 plys. Hard tooling was used for the inside mandrel (aluminum) and soft tooling was used for the outside diameter (Teflon shrink tube).

It was concluded from this effort that the use of outside soft tooling is satisfactory for boron-epoxy tubes. The following describes the processing involved in fabricating the tubes and of the bonding of the fittings to them.

Process Summary - The boron-epoxy cylinder specimens for this Phase I study were fabricated by a process which was intended for use in any Phase II prototype cylinders fabricated from boron-epoxy. The tape or broad goods in each lamina is of continuous length for the full length of the cylinder. The only discontinuities in the filaments are splices of single filaments which are a part of the processing by the boron filament vendor and/or Hercules' broad goods manufacturing process. These splices are in the order of one per 3500 feet or more of filament length. The longitudinal or 0° lamina was formed by wrapping a single sheet of broad goods around the mandrel. The 45° lamina was formed by wrapping a single strip of broad goods, cut on a 45° bias, around the mandrel such that all fibers are continuous for the full tube length. The circumferential or 90° lamina was formed by filament winding with two boron filaments to a spacing of 216 filaments per inch.

The following is typical of the processing used to fabricate tubes.

1. Apply release agent to aluminum mandrel.

2. Remove release paper from one side of broad goods oriented for 0°.

3. Wrap broad goods around mandrel.

4. Rotate mandrel 180° and wrap second 0° layer.

5. Wrap layer of BP-907 supported resin around laminates.

6. Consolidate 0° layers by application of vacuum bag and heat lamps.

7. Remove vacuum bag.

8. Wind 90° layer with two boron wires.

9. Remove release paper from one side of broad goods oriented for +45°.

10. Wrap helically one layer of +45° broad goods.

11. Remove release paper from one side of broad goods oriented for -45°.

12. Wrap helically one layer of -45° broad goods.

13. Consolidate composite by application of vacuum bag and heat lamps.

14. Repeat steps 2 through 13 until desired number of lamina is obtained.

15. After last consolidation step, prepare for autoclave as follows:

    a. Shrink Teflon tube over composite.

b. Wrap coarse porous Armalon over Teflon tube.

c. Install thermocouple and vacuum tube.

d. Install two vacuum bags.

16. Autoclave cure as follows:

a. 50 psi.

b. 730 mn Hg vacuum.

c. 180 - 190°F 1/2 hour.

280 - 290°F 1/2 hour.

350 - 360°F 1 hour.

d. Allow to cool down to 200°F with vacuum and pressure.

e. Remove part when temperature is below 120°F.

17. Disassemble mandrel assembly.

18. Inspection.

TEN-PLY TUBE

A ten-ply specimen, (Figure 5-57), was made to check out the tooling and to confirm the fabrication process. It was suspected that soft tooling could be used for the outside diameter of the tubes and thus reduce costs by using a hard internal mandrel and an expendable exterior mandrel for several designs. To verify this belief, a Teflon shrink tube was used as the outside tooling. Adequate control of tolerances and surface finish was demonstrated, confirming that soft tooling could be used for this work. The ply layup sequence was as follows: two 0° plies, one 90° ply, one +45° ply, one -45° ply, one -45° ply, one +45° ply, one 90° ply, two 0° plies.

The step by step procedure of the fabrication of the ten-ply tube is as follows.

1. Tooling

a. Aluminum 6061-3 inches OD x 2 1/2 inches ID pipe.

b. Machined to 2.806 inches OD (2.805-2.807).

c. 18 inches machined surface usable.

d. Plugged one end of pipe for tail stock center.

2. Broad Goods

a. One piece 37 inches x 24 inches for 0° layups.

b. One piece 37 inches x 30 inches for 45° layups.

3. Fabrication Procedure

Step A. 0° Layers

1 Release coat mandrel.

2 Remove release paper from one side of broad goods.

3 Wrap broad goods around mandrel.

4 Rotate mandrel 180° and wrap second 0° layer.

5 Wrap layer of BP-907 supported resin around laminates.

Step B. Consolidate 0° Layers.

Step C. 90° Layer

1 Wind 90° boron.

Step D. 45° Layers.

1 Measure diameter to determine actual circumference of composite.

2 Remove release paper.

3 Wrap helically.

4 After one +45° and one -45° layer, repeat consolidation step.

5 Wrap two 45° layers.

6 Consolidation step repeated.

Step E. 90° Layer

1 Repeat Step C.

Step F. 0° Layers

1 Cut broad goods 0.150 inch over size on πD based on OD of composite after last 90° layer.

2 Compaction step repeated.

3 Layup last 0° layer

4 Compact.

Step G. Autoclave Preparation

1 Remove consolidation material.

2 Shrink Teflon tube over composite.

3 Wrap coarse porous Armalon.

4 Install thermocouple and vacuum tube.

5 Install two vacuum bags.

Step H. Autoclave Cure

1 50 psi.

2 730 mm Hg vacuum.

3 180-190 1/2 hour.

4 280-290 1/2 hour.

5 350-360 1 hour.

6 Allow to cool down to 200° F with vacuum and pressure.

7 Remove part when temperature is below 120° F.

Step I. Disassembly from Mandrel

1 Remove vacuum bags.

2 Remove Armalon.

3 Remove Teflon shrink tube.

4 Use tool holder grinder to trim ends off composite using diamond wheel.

Step J. Part Quality Check

1 Resin content.

2 Appearance.

3 Length.

4 OD.

5 ID.

6 Concentricity.

7 Wall thickness.

Fittings

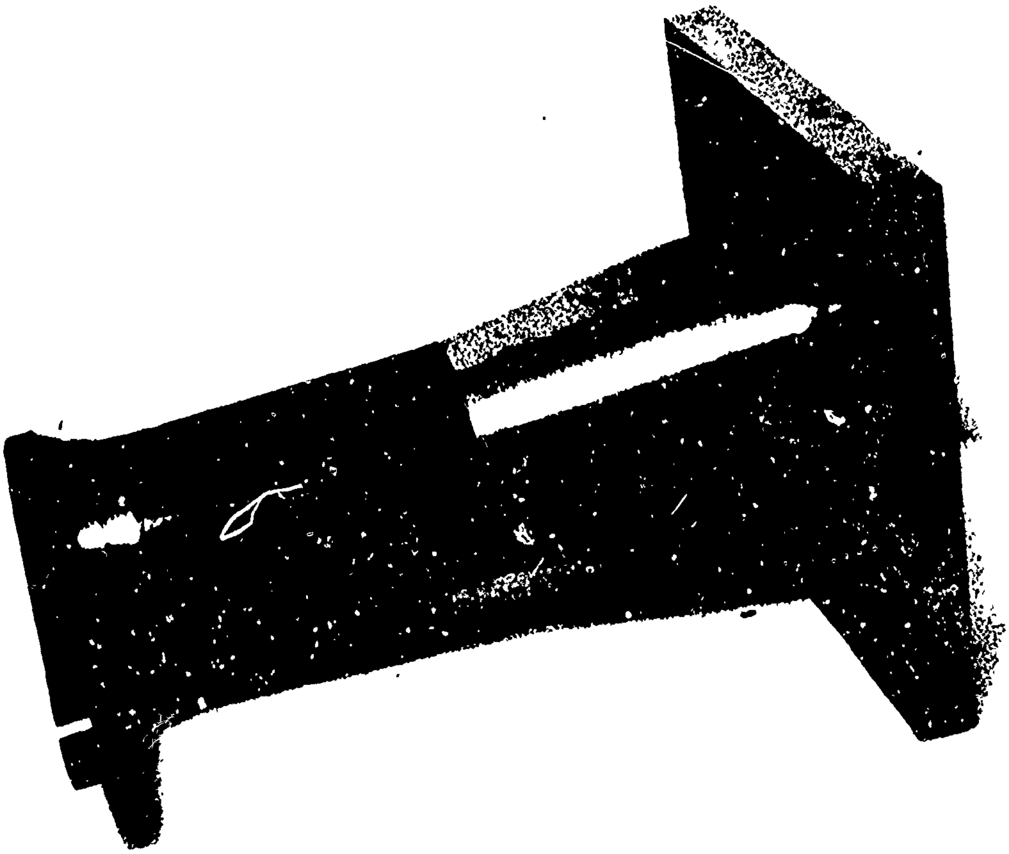
Bendix supplied Hercules the 4340 steel end fittings to be bonded to the ten-ply tube. The ID of the end fittings was tapered 0.100 inch per foot and the ends of the boron tube were ground to fit this taper. The joint adhesive, FM-1000, was precut and secured on the tapered surfaces. The end caps were placed on their respective ends and an axial load was applied to the ends of the tube to press the fittings in place. The adhesive joints were cured one-half hour at 350° F. A detailed description of the bonding procedure is given below.

Photographs of the individual parts and the specimen assembly are shown in Figure 8-57.

Bonding Problems

The loading lug on the ten-ply tube failed prematurely during the testing at Bendix. The mode of failure was cohesive between the metal lug and the FM-1000 adhesive. A review of cleaning and bonding procedures were undertaken by Hercules to insure proper adhesion on future test specimens.

Component Parts of Outer Cylinder



Assembly of Outer Cylinder Specimen

Figure 8-57. Boron-Epoxy Outer Cylinder Specimen, Ten-Ply

Hercules conducted two series of tests using one inch wide by 0.061 inch thick 4130 steel strips with 1/2 inch overlap. The first test specimens were made using FM-1000 without a scrim cloth and the second group of specimens used a nylon scrim cloth.

Test Specimens - Group I

The four specimens were prepared with FM-1000 adhesive and were cured at 305°F for 1-1/2 hours under approximately 200 psi pressure, applied by "C" clamps. The adhesive thickness was 0.007 inch before cure and was reduced to approximately 0.0005 inch during cure.

Nondestructive tests using the Fokker bond tester showed good bonds with no abnormalities.

Test results on the four specimens showed that all failures were adhesive and the lap shear strength of the specimens were:

4750 psi
4440 psi
5350 psi
5280 psi

Average - 4955 psi

Tentative Conclusions

The surface preparation used for the 4130 steel appears to be adequate in that the failure was adhesive and not cohesive. Lower bonding pressure and higher cure temperatures are recommended. The use of scrim in the FM-1000 to maintain proper adhesive thickness is also recommended.

Test Specimens - Group II

Eight additional lap shear specimens were fabricated and tested to determine the effect of using nylon scrim in FM-1000 adhesive. Four of the eight scrim/FM-1000 specimens were bonded at 350°F using a 50 psi dead weight during cure. The lap shear test results were disappointing in that there was considerable scatter (between 1040 and 5040 psi). The failures appeared partially cohesive and partially adhesive. The remaining four specimens were made using the described cleaning and curing procedures except that a higher pressure was used during cure (200 psi). Test data were much more uniform, the average being 4400 psi, but high percentage of failures occurred in the adhesive. Apparently, a greater pressure than 50 psi is required in curing lap joints containing FM-1000 with scrim.

Bonding to Ten-Ply Cylinder

The metal lug attachment was cleaned and rebonded to the ten-ply tube using FM-1000 with nylon scrim cloth. The specimen was shipped to Bendix for final testing.

The exact process used to bond the lug to the cylinder is as follows.

I. Machining of Boron Tube

A. Boron tube installed on mandrel.

B. Tube and mandrel chucked up in lathe.

C. Taper attachment set for 0.022 1/2 inch per three inches (0.045 on diameter).

D. Dumore grinder setup with diamond wheel.

E. Taper ground on one end of tube.

1. Small end of taper - 2.862 inches.

2. Large end of taper - 2.907 inches.

F. Move tube out 8 1/2 inches and cut off.

G. Set up other end of tube and ground taper.

1. Small end of taper - 2.898 inches.

2. Large end of taper - 2.906 inches.

II. End Caps Preparation

A. Blasted bond surfaces with steel grit.

B. Blasted surfaces cleaned with solvent.

C. Dried for 1/2 hour @ 150° F.

III. Tube Preparation

A. Clean taper surfaces with solvent.

B. Dried for 1/2 hour @ 150° F.

C. Taper surfaces painted with HR-1009-8 primer and air dried for 1/2 hour at R.T.

D. Precut FM-1000 resin secured on taper surfaces.

IV. Assembly

A. End caps placed on respective end.

1. Torque arm on 1.300 inches end.

2. Base plate on 3.000 inches end.

B. End oriented as instructed by phone conversation with Bendix.

C. Assembly put in press and pressed into position.

D. FM-1000 slipped in on both end.

1. Reduced bond area.

a. Torque arm - 7.30 in^2.

b. Base plate - 23.6 in^2.

2. Bond line perimeter still square.

V. Cure

A. Heated up to 350° F in one hour.

B. Held at 350° F one hour.

C. Allowed to cool in oven overnight.

FORTY-EIGHT-PLY TUBE

This tube is part of the assembly illustrated in Figure 5-58. This item was fabricated by the same general process as used for the ten-ply tube. The details are as follows.

Mandrel Preparation

1. Clean mandrel.
2. Apply mold release.
3. Bake for 1/2 hour at 350°.

Tube Layup

Step A

1. Apply 0° layers.
2. Apply a sheet of supported BP-907 resin.
3. Apply Armalon and vacuum bag.
4. Heat.
5. Let cool.
6. Remove vacuum bag and Armalon.

Step B

1. Wind 90° layer.

Step C

1. Apply +45° and -45° layers.
2. Repeat A-3, 4, 5, and 6.

Step D

Repeat Steps A, B and C.

Step E

Repeat Steps A, B and C.

Step F

Repeat Steps A, B and C.

Step G

1. Apply -45° and +45° layers.
2. Repeat A-3, 4, 5 and 6.

Step H

Repeat Steps B, A and G.

Step I

Repeat Steps B, A and G.

Step J

Repeat Steps B, A and G.

Step K

Repeat Steps A-2, 3 and 4.

Step L

Repeat Steps A-2 and 3. Install in autoclave and B-stage.

Step M

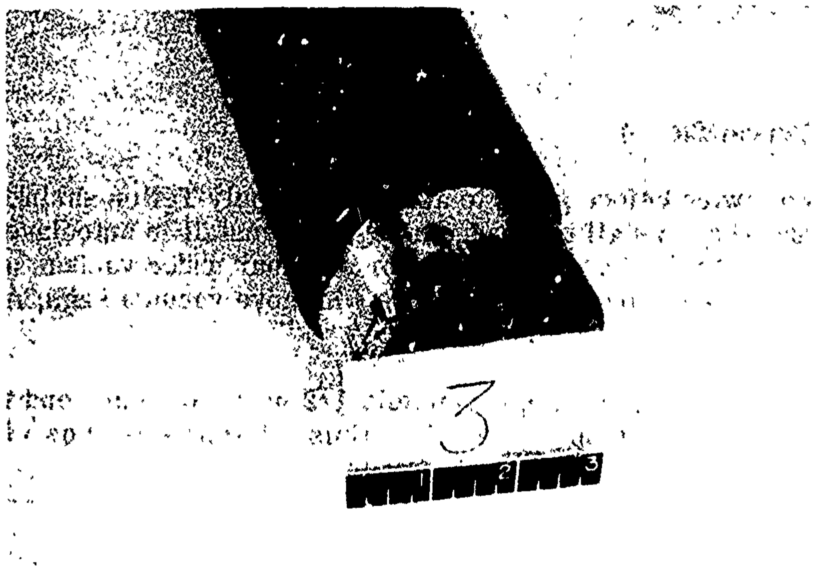
Repeat Step B.

Step N

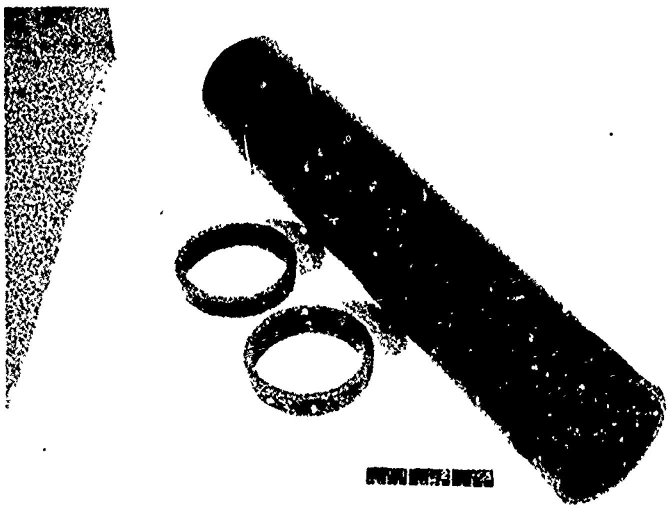
Repeat Step A

This is done twice before going to autoclave. Apply Teflon shrink tube. Install coarse Armalon on tube. Install two vacuum bags and install in autoclave. Cure at 180° for 1/2 hour, 280° for 1/2 hour and 350° for one hour under vacuum and 50 psi. Let cool to 150° before removing from autoclave. Remove vacuum bags, Armalon and Teflon shrink tube.

Install a lathe and remove approximately 1/2 inch from each end with a Dumore tool post grinder and a diamond wheel. The finished article is shown in Figure 8-58.



Before Removal from Mandrel



After Removal from Mandrel

Figure 8-58. Photograph of Boron-Epoxy Forty-Eight-Ply Tube

Fittings - Original Design, Figure 5-58 (48 Ply Tube)

A set of attachments was shipped to Hercules by Bendix. A taper was ground on the forty-eight-ply boron tube to match the taper in the end fittings. A gap of 0.005 inch was provided between the fitting and the tube for the FM-1000 adhesive with scrim cloth. In cutting the tube to length, the ends were slightly beveled. The metal parts were grit blasted in the bonding area, cleaned and bonded to the tube. A press was used to ensure a slight load and to align the parts. However, the curing temperature was not uniform and to obtain a minimum temperature of 325° F, the platen temperature reached 400° F. When load was applied with the hot platen, delamination occurred over an area approximately 3/4 inch long and 1/2 inch wide on the inner three plies. Even though this normally should not adversely affect the test, room-temperature curing resin (828) was injected into the gap and the inner plies were rebonded.

Tentative Conclusions

The adhesive used to bond the metal attachments to the boron-epoxy tube should not be cured in the press because of the large variation in cure temperatures and because of the possibility of damaging the tube. It is recommended that the adhesive be cured in the oven utilizing the press for initial alignment and weights on the part to provide pressure.

Inspection

The forty-eight-ply tube assembly was shipped to Automation Industries, Danbury, Connecticut, for inspection. Two inspection techniques, through transmission and pulse echo, were used with the C-scan ultrasonic inspection equipment. The thru-transmission records the ultrasonic signal after passing through the specimen. The pulse-echo records the reflected signal. Any reduction in either the thru-transmission or reflection signal is indicative of delamination or debonding. The reduced energy is caused by absorption or scatter within the material being tested. No standard procedures or standard test samples were available for either setting up the equipment or verifying the test results. The inspections were conducted on a "best efforts" basis. A total of nine C-scans were obtained, and one scan, representing the summation of the best inspection effort, is displayed in Figure 8-59.

The thru-transmission inspection records revealed one area of possible delamination in the wall of the tube approximately one-inch wide starting 2-3/8 inches from the top and continuing down the length of the tube. Also, 90° from this area, a potential region of intermittent delamination was found. The location of the delamination within the tube wall (depth location) was not determined.

Pulse-echo techniques were tried to determine the degree of unbond between the composite tube and the steel fittings. No success was obtained with the signal emanating from the composite side of the bond. Limited success was obtained with the signal passing through the steel. Only those areas which had no protrusion could be inspected with this technique. Results indicate satisfactory bonds between the composite and the steel.

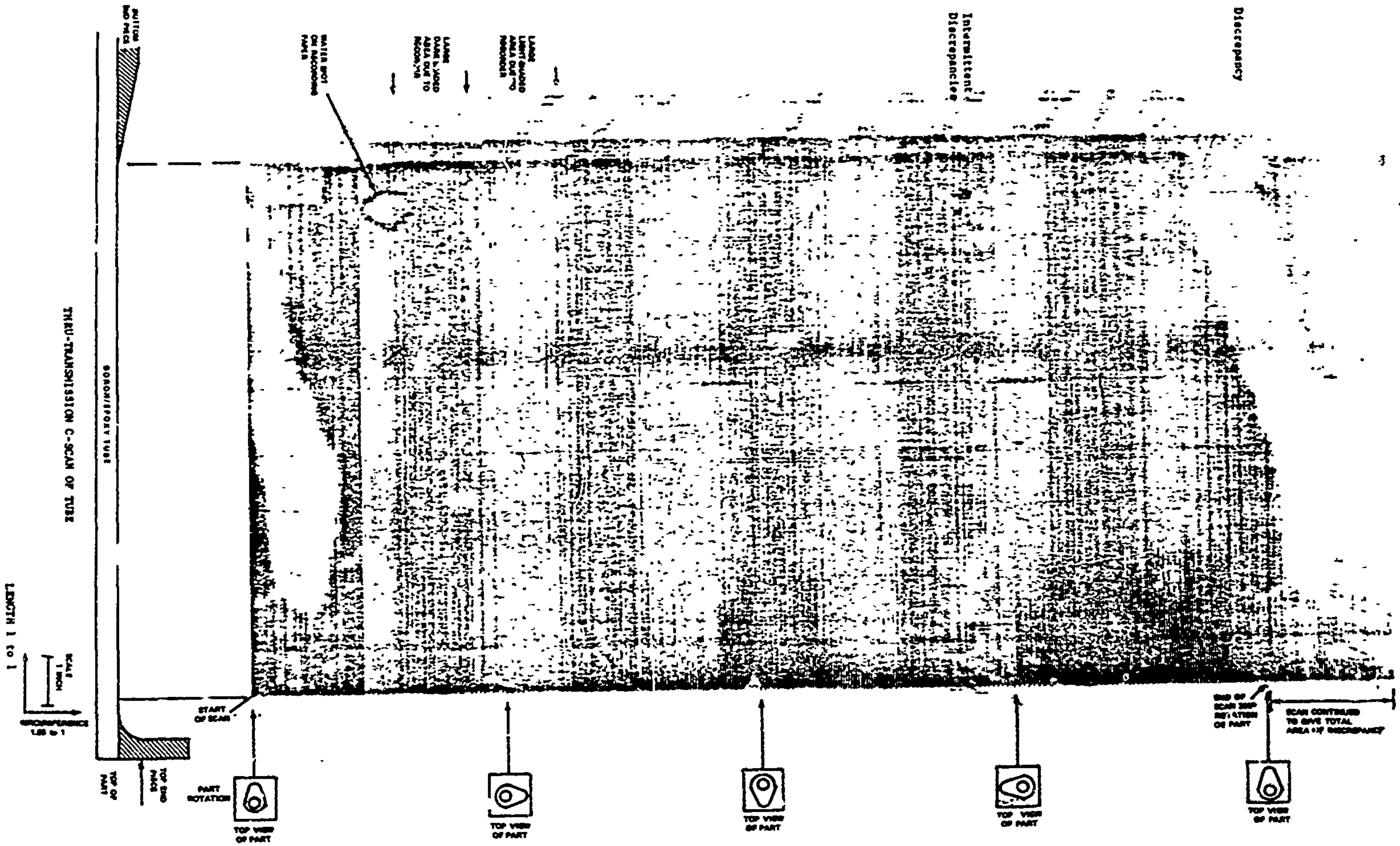


Figure 8-59. C-Scan Inspection of Forty-Eight-Ply Tube

Fittings - Second Design, Figure 5-69 (48 Ply Tube)

The steel trunnion end fitting was reworked by machining out the back face and removing metal from the ID to form a reverse taper. The fitting was then reheat treated to 260-280 ksi UTS.

The tube was reworked by wrapping a 0°, 90° glass epoxy reinforcement over the end. The wrapping process was as follows.

1. Wrap four circumferential layers of S glass with a tension of 18 pounds per 20 ends.

2. Apply one layer of 181 glass cloth with the fibers running 0° and 90°.

3. Repeat the above sequence four times.

4. Finish with two circumferential layers of S glass.

5. Resin: Epon - 828 100 parts by weight
   Z 20 parts by weight

6. Cure at 150° F for 12 hours.

7. Machine end taper to match fitting.

The fitting was next assembled to the tube. A urethane cushion was applied between the tube and fitting according to the following procedure.

Urethane Application

A 0.020 inch thick layer of urethane is used to separate the steel and filament composite surfaces of the joint. It is important that the thickness of the layer be uniform throughout the entire joint area. The following procedure ensures control of the layer thickness.

1. Mixing and Curing Procedure.

   167 Urethane - 100 PBW (Parts By Weight)
   Moca - 20 PBW

   Cure cycle - 150° F for two hours, then seven days at room temperature.

2. Cast a flat sheet of urethane 0.022 ± 0.001 inch thick. Cure as indicated in Step 1. Cut into 0.25 inch wide strips, with length as required, to be used as shims.

3. Clean surfaces of both the metal fitting and the composite tube by dry sanding just prior to assembly.

4. Apply the shims to the conical portion of the composite tube in the joint area. Locate the shims axially and spaced 120° around the circumference. Apply freshly mixed urethane to both joint surfaces in sufficient quantity to completely fill the 0.022 inch radial gap which will exist between mating surfaces.

5. Push the tube into the metal socket until the shims bottom out against the conical surface and have compressed approximately 0.001 to 0.002 inch. The urethane mixture should completely fill the radial gap and the excess squeezed out.

6. Cure as indicated in Step 1.

Fittings - Third Design, Figure 5-73 (48 Ply Tube)

After completion of the test on the Second Design a major portion of the cylinder and the loading lug joint were still intact. The Third Design was fabricated by cutting off the broken end of the tube and attaching the fitting by the same procedure as described above for the Second Design.

THIRTY-TWO-PLY TUBE

The outer cylinder specimen associated with this tube is shown in Figures 5-77 and 78. The basic process developed during fabrication of the Ten-Ply tube was used here. The details are as follows.

Fabrication Process

Step A

1. Release coat mandrel.
2. Install in lathe.
3. Remove release paper from one side of broad goods.
4. Wrap broad goods around mandrel.
5. Remove green release paper.

Step B

1. Wrap tube with porous Armalon.
2. Wrap vacuum bag and pull vacuum.
3. Heat with heat gun.
4. Let mandrel cool to room temperature.
5. Remove vacuum bag and Armalon.

Step C

1. Wind 90° layer.

Step D

1. Install +45, -45 and 0° layers.
2. Repeat Step B.

Step E

1. Wind 90° layer.
2. Wrap tube with coarse porous Armalon.
3. Install vacuum bag.
4. Autoclave, B-stage.
5. Remove from autoclave.

Step F

1. Install +45° layer.
2. Repeat Step B.

Step G

1. Install -45° and 0° layer.
2. Repeat Step B.

Step H

1. Wind 90° and install +45° layer.
2. Repeat Step B.

Step I

1. Install -45 and 0° layer.
2. Repeat Step B.

Step J

1. Wind 90° and install +45 and -45° layers.

2. Repeat Step B.

Step K

1. Install -45 and +45° layers.

2. Repeat Step B.

Step L

1. Wind 90° and install 0° layer.

2. Repeat Step B.

Step M

1. Install -45 and +45° layers.

2. Repeat Step B.

Step N

1. Wind 90° layer and install 0° layer.

2. Repeat Step B.

Step O

1. Install -45 and +45° layers.

2. Repeat Step B.

Step P

1. Wind 90° and install 0° layers.

2. Repeat Step B.

Step Q

1. Install -45 and +45° layers - Autoclave.

2. Repeat Step E.

Step R

1. Wind 90° layer and install 0° layer.

Step S

1. Repeat Step R.

Step T

1. Shrink Teflon tube on mandrel.

Step U

1. Prepare for autoclave.

Step V

1. Autoclave cure.
2. 50 psi.
3. 700 mm Hg vacuum.
4. 180-190° F for 1/2 hour
5. 280-290° F for 1/2 hour
6. 350-360° F for one hour.

Step W

1. Disassemble.

Step X

1. Trim.

Tube #1 - 32 Plies - 0, 90, ±45 (8 times)

	End 1	End 2
ID	2.813	2.811
	2.915	2/9;5
OD	3.117	3.108
	3.119	3.110

$$\text{Density} = 0.075 \text{ lb./in.}^3$$

$$= 2.08762 \text{ Sp Gr}$$

Tube #1

32 plies Boron = 0.0039

$$0.0039 \text{ dia.} = 3.9 \times 10^{-3}$$

$$\text{Area} = \frac{\pi}{4}(3.9)^2 \times 10^{-6} = 11.94590 \times 10^{-6}$$

$$\underset{\text{one ply one inch}}{\text{Volume}} = 216A = 2.5803144 \times 10^{-3}$$

$$\underset{\text{32 plies}}{\text{Volume}} = 32 \times V = 0.08257$$

$$\underset{\text{Total}}{\text{Volume}} = 0.153 \qquad \%\text{ fiber} = 53.97 \text{ Volume}$$

$$0.004 \text{ dia.} =$$

$$\text{Area} = 12.56636 \times 10^{-6}$$

$$\text{Volume} = 32 \times 216 \times 12.56636 \times 10^{-6}$$

$$r = 0.086859$$

$$\%\text{ fiber} = 56.77\% \text{ Volume}$$

After fabrication the cylinder was inspected by the ultrasonic C-scan method.

Figure 8-60 is a C-scan presentation of the thru-transmission ultrasonic inspection of a thirty-two-ply boron filament/BP-907 epoxy tube. This inspection was performed at Automation Industries, Danbury, Connecticut, and was conducted as a "best efforts" basis since no test standards for defects could be supplied.

Basically the light areas of the presentation represent a 40 percent or greater loss in the transmitted signal. Any reduction in the thru-transmission signal is indicative of delaminations, debonding or some change in material consistency. The reduced energy is caused by absorption or scatter within the material being tested.

Due to the length of the part two scans were necessary, thus, the attached scan is a composite of the two scans. The area of overlap is marked on the attached presentation.

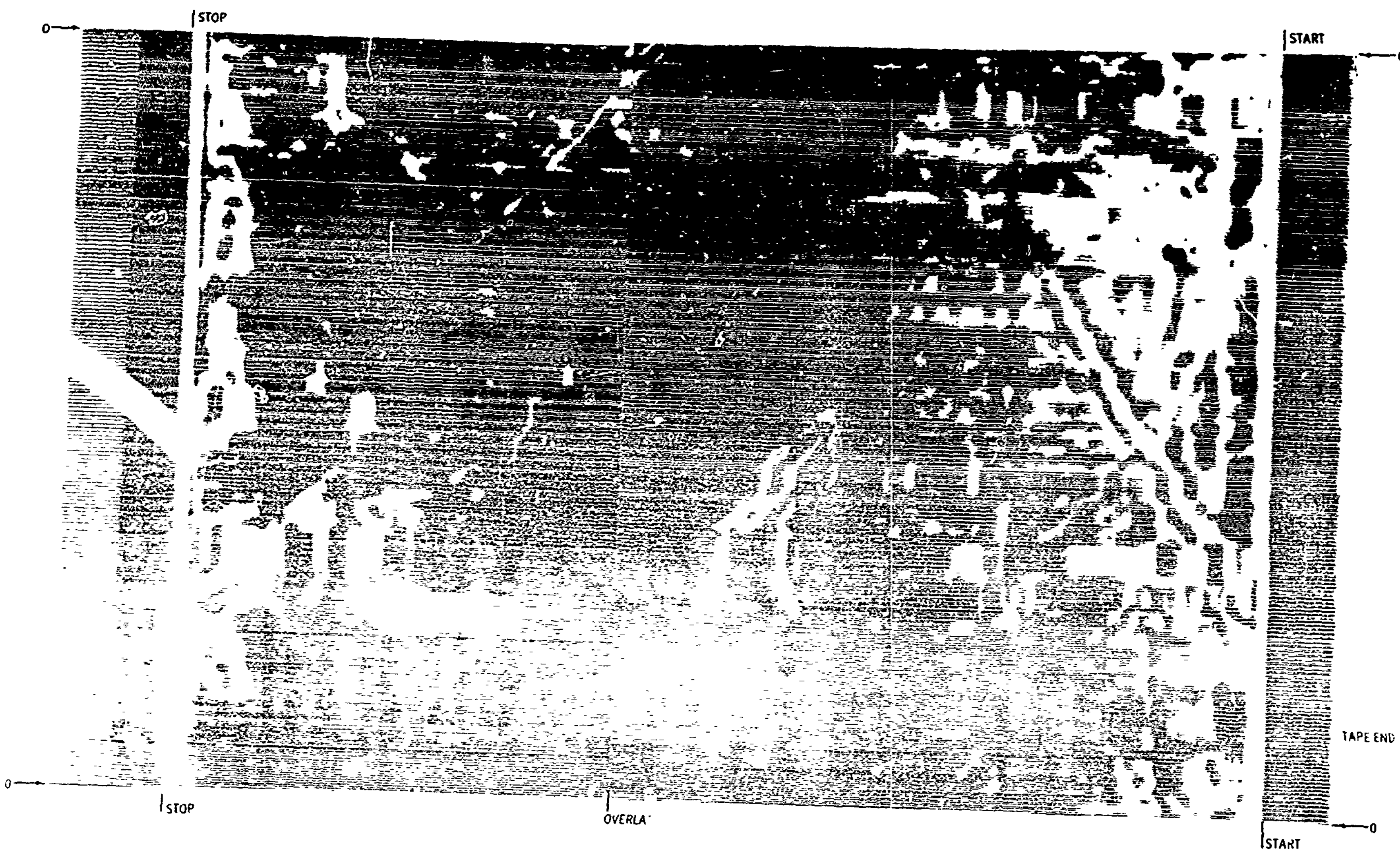


Figure 8-60. C-Scan Inspection, Thirty-Two-Ply Tube Specimen

8.2.5.2 Fabrication of the Boron-Epoxy Prototype Outer Cylinder Assembly

This item is illustrated in Figure 8-61. The design details are discussed in Paragraphs 5.3.1.3 and 6.4.

The boron-epoxy cylinder was fabricated by Hercules. Bendix effort dealt with machining of the composite cylinder, procurement of the conventional metallic fittings and assembly of all parts into the final outer cylinder - trunnion assembly.

1. Hercules Activities

The Hercules effort consisted of fabrication of the cylinder illustrated in Figure 8-62.

Fabrication Process for Outer Cylinder VXD-31089

1. Prepare aluminum mandrel.

    a. Clean

2. Obtain nickel plating (reference Paragraph 8.2.6).

3. Clean nickel plating:

    a. Measure diameter and TIR three places.

    b. Scotchbrite.

    c. Degrease surface.

    d. Water break test.

4. Fabricate broadgoods $\approx$100 ft^2.

5. Apply lamina in the following sequence:

    a. Apply 20% BR 1009 to surface.
    Apply sheet of resin to nickel surface.

    b. Apply three 0° plies (20" long).

    c. Consolidate.

        (1) Apply Armalon.
        (2) Apply vacuum bag.
        (3) Wrap glass overwrap.
        (4) Heat surface, 180°F approximately.
        (5) Cool to room temperature.
        (6) Remove glass.
        (7) Remove vacuum bag.
        (8) Clean surface with tri-clean of any foreign particles.
        (9) Allow to evaporate.
        (10) Measure and record diameter and TIR at three locations.

d. Apply 90° wrap (heat surface while winding).

e. Apply sheet resin and consolidate.

f. Apply $\pm$ 45° wrap.

g. Consolidate.

h. Apply three 0° plies.

i. Consolidate.

j. Apply 90° wrap (heat while winding).

k. Apply sheet resin and consolidate.

l. Apply $\pm$ 45° wrap.

m. Consolidate.

n. Apply three 0° plies.

o. Consolidate.

p. Apply 90° wrap (heat while winding)

q. Apply sheet of resin and consolidate.

r. Apply $\pm$ 45° wrap.

s. Consolidate.

t. Apply three 0° plies.

u. Consolidate.

v. Apply 90° wrap (heat while winding).

w. Apply sheet of resin and consolidate.

x. Apply $\pm$ 45° wrap.

y. Consolidate.

z. Apply three 0° plies.

aa. Consolidate.

ab. Apply 90° wrap (heat while winding).

ac. Apply sheet of resin and consolidate.

ad. Apply $\pm$ 45° wrap.

ae. Consolidate.

af. Apply three 0^{o} plies.

ag. Consolidate.

ah. Apply 90^{o} wrap (heat while winding).

ai. Apply sheet of resin and consolidate.

aj. Apply $\pm 45^{o}$ wrap.

ak. Consolidate.

al. Apply three 0^{o} plies.

am. Consolidate.

an. Apply 90^{o} wrap (heat while winding).

ao. Apply sheet of resin and consolidate.

ap. Apply $\pm 45^{o}$ wrap.

aq. Consolidate.

ar. Apply three 0^{o} plies.

as. Consolidate.

at. Apply 90^{o} wrap (heat while winding).

au. Apply sheet of resin and consolidate.

av. Apply $\pm 45^{o}$ wrap (10.7 and 10.5" long piece).

aw. Consolidate (remove only material over $\pm 45^{o}$ plies).

ax. Apply three 0^{o} plies (10.3", 10.1", 9.9" long piece).

ay. Consolidate over 0^{o} plies.

az. Apply 90^{o} wrap (heat while winding) 10.7".

ba. Apply sheet of resin and consolidate.

bb. Apply $\pm 45^{o}$ wrap (9.9" and 9.7" long piece).

bc. Consolidate over last 10.7", remove 9.9".

bd. Apply three 0^{o} plies (9.7", 9.5", 9.3" long piece).

be. Consolidate over 0^{o} plies.

bf. Apply 90^{o} wrap - 9.9" (heat while winding).

bg. Apply sheet of resin and consolidate.

bh. Apply $\pm$ 45° wrap (9.3" and 9.1" long piece)

bi. Consolidate over last 9.9", remove 9.3".

bj. Apply three 0° plies (9.1", 8.9", 8.7" long).

bk. Consolidate over 0° plies.

bl. Apply 90° wrap (9.3" long) (heat while winding).

bm. Apply sheet of resin and consolidate.

bn. Apply $\pm$ 45° wrap (8.7", 8.5" piece).

bo. Consolidate over last 9.3", remove 8.7".

bp. Apply three 0° plies (8.5", 8.3", 8.1" long).

bq. Consolidate over 0° plies.

br. Apply 90° wrap.

bs. Apply sheet of resin and consolidate.

bt. Apply three 0° over entire surface.

bu. Check dimension of O.D. If greater than 3.900" and ovality less than 0.020", winding is complete. If not, call engineer in charge for direction. Consolidate.

bv. Apply vacuum for 8 hours minimum.

6. Apply teflon shrink tubing. Follow manufacturers instructions.

7. Apply two wraps of TX-1040 teflon coated glass scrim to surface of tubing.

8. Apply one wrap of Armalon over the TX-1040.

9. Apply thermocouple.

10. Install vacuum bag over unit.

11. Place in autoclave.

12. Cure per following sequence with 50 to 100 psi and full vacuum:

    a. 1/2 hour at 180° F.

    b. 1/2 hour at 280° F.

    c. 1 hour at 350° F.

    d. Cool under pressure and vacuum.

13. Remove part from autoclave.

14. Remove composite from mandrel.

15. Ship to Automation Industries for C-scan.

16. Ship to Bendix.

    (a) The nickel plated mandrel is shwon in Figure 8-63.

    (b) The 0° and 45° lamina were applied by hand layup of uni-directional broad goods. The 90° lamina were applied by the circumferential winding of two filaments at 108 turns per inch. The tensile load applied to the filaments during winding was approximately 85% of the breaking strength of the filaments under winding conditions.

    (c) Vacuum used during the consolidation and curing operations was between 24 and 25 inches Hg. (Bacchus, Utah)

    (d) The dimensional results after each consolidation step are given in Table 8-3.

The completed outer cylinder tube as furnished by Hercules is illustrated in Figures 8-64, 8-65 and 8-66.

After fabrication, the composite tube was shipped to Automation Industries, Danbury, Connecticut, for C-scan inspection. The results are shown in Figure 8-67.

TABLE 8-3. CONSOLIDATION STEPS - DIMENSIONAL CHECKS

	LOCATION 1 LEFT			LOCATION 2 CENTER			LOCATION 3 RIGHT		
	0° Dia.	90° Dia.	Diff.	0° Dia.	90° Dia.	Diff.	0° Dia.	90° Dia.	Diff.
1st Consol., Step c (3-0°)	3.294	3.295	0.001	3.294	3.295	0.001	3.2945	3.294	0.0005
2nd Consol., Step e (90°)	3.304	3.304	0	3.304	3.304	0	3.3045	3.305	0.0005
3rd Consol., Step g (± 45°)	3.326	3.326	0	3.327	3.326	0.001	3.326	3.327	0.001
4th Consol., Step i (3-0°)	3.355	3.355	0	3.356	3.356	0	3.355	3.355	0
5th Consol., Step k (90°)	3.365			3.366			3.366		
6th Consol., Step m (± 45°)	3.386	3.385	0.001	3.387	3.386	0.001	3.387	3.387	0
7th Consol., Step o (3-0°)	3.415	3.415	0	3.416	3.416	0	3.416	3.416	0
8th Consol., Step q (90°)	3.424	3.425	0.001	3.426	3.426	0	3.426	3.426	0
9th Consol., Step s (± 45°)	3.445	3.445	0	3.447	3.447	0	3.446	3.446	0
10th Consol., Step u (3-0°)	3.472	3.473	0.001	3.472	3.473	0.001	3.472	3.475	0.003
11th Consol., Step w (90°)	3.483	3.483	0	3.483	3.484	0.001	3.484	3.485	0.001
12th Consol., Step y (± 45°)	3.502	3.501	0.001	3.502	3.502	0	3.502	3.503	0.001
13th Consol., Step aa (3-0°)	3.531	3.531	0	3.532	3.532	0	3.532	3.533	0.001
14th Consol., Step ac (90°)	3.537	3.537	0	3.541	3.540	0.001	3.540	3.542	0.002
15th Consol., Step ae (± 45°)	3.559	3.559	0	3.562	3.562	0	3.563	3.562	0.001
16th Consol., Step ag (3-0°)	3.590	3.589	0.001	3.591	3.590	0.001	3.592	3.590	0.002
17th Consol., Step ai (90°)	3.597	3.598	0.001	3.599	3.598	0.001	3.601	3.601	0
18th Consol., Step ak (± 45°)	3.618	3.617	0.001	3.621	3.619	0.001	3.621	3.618	0.003
19th Consol., Step am (3-0°)	3.648	3.647	0.001	3.650	3.649	0.001	3.649	3.648	0.001
20th Consol., Step ao (90°)	3.657	3.659	0.002	3.660	3.660	0	3.660	3.659	0.001
21st Consol., Step aq (± 45°)	3.680	3.679	0.001	3.682	3.679	0.003	3.680	3.679	0.001
22nd Consol., Step as (3-0°)	3.712	3.711	0.001	3.714	3.712	0.002	3.713	3.711	0.002
23rd Consol., Step au (90°)	3.721	3.720	0.001	3.725	3.723	0.002	3.722	3.720	0.002
24th Consol., Step aw (± 45°)	3.743	3.742	0.001	3.744	3.742	0.002	3.742	3.741	0.001
25th Consol., Step ay (3-0°)	3.768	3.769	0.001	3.770	3.772	0.002	3.771	3.770	0.001
26th Consol., Step ba (90°)	3.777	3.778	0.001	3.779	3.781	0.002	3.780	3.781	0.001
27th Consol., Step bc (± 45°)	3.800	3.798	0.002	3.800	3.801	0.001	3.802	3.801	0.001
28th Consol., Step be (3-0°)	3.830	3.828	0.002	3.829	3.831	0.002	3.831	3.830	0.001
29th Consol., Step bg (90°)	3.837	3.839	0.002	3.839	3.840	0.001	3.839	3.839	0
30th Consol., Step bi (± 45°)	3.857	3.858	0.001	3.859	3.860	0.001	3.860	3.858	0.002
31st Consol., Step bk (3-0°)	3.889	3.888	0.001	3.887	3.890	0.003	3.889	3.890	0.001
32nd Consol., Step bm (90°)	3.896	3.898	0.002	3.898	3.897	0.001	3.898	3.896	0.002
33rd Consol., Step bo (± 45°)	3.916	3.917	0.001	3.917	3.916	0.001	3.918	3.918	0
34th Consol., Step bq (3-0°)	3.946	3.948	0.002	3.945	3.947	0.002	3.946	3.946	0
35th Consol., Step bs (90°)	3.957	3.957	0	3.956	3.956	0	3.957	3.956	0.001
36th Consol., Large, Step bu (3-0°)	3.980	3.984	0.004	3.984	3.986	0.002	3.985	3.984	0.001
Small, (3-0°)	3.753	3.751	0.002	3.753	3.752	0.001	3.752	3.751	0.001
After Vac., Step bv Large	3.986	3.986	0	3.985	3.985	0	3.986	3.984	0.002
Small	3.755	3.753	0.002	3.752	3.751	0.001	3.752	3.750	0.002
After Cure, Step bv Large	3.970	3.969	0.001	3.978	3.980	0.002	3.979	3.980	0.001
Small	3.745	3.755	0.010	3.745	3.749	0.004	3.730	3.735	0.005

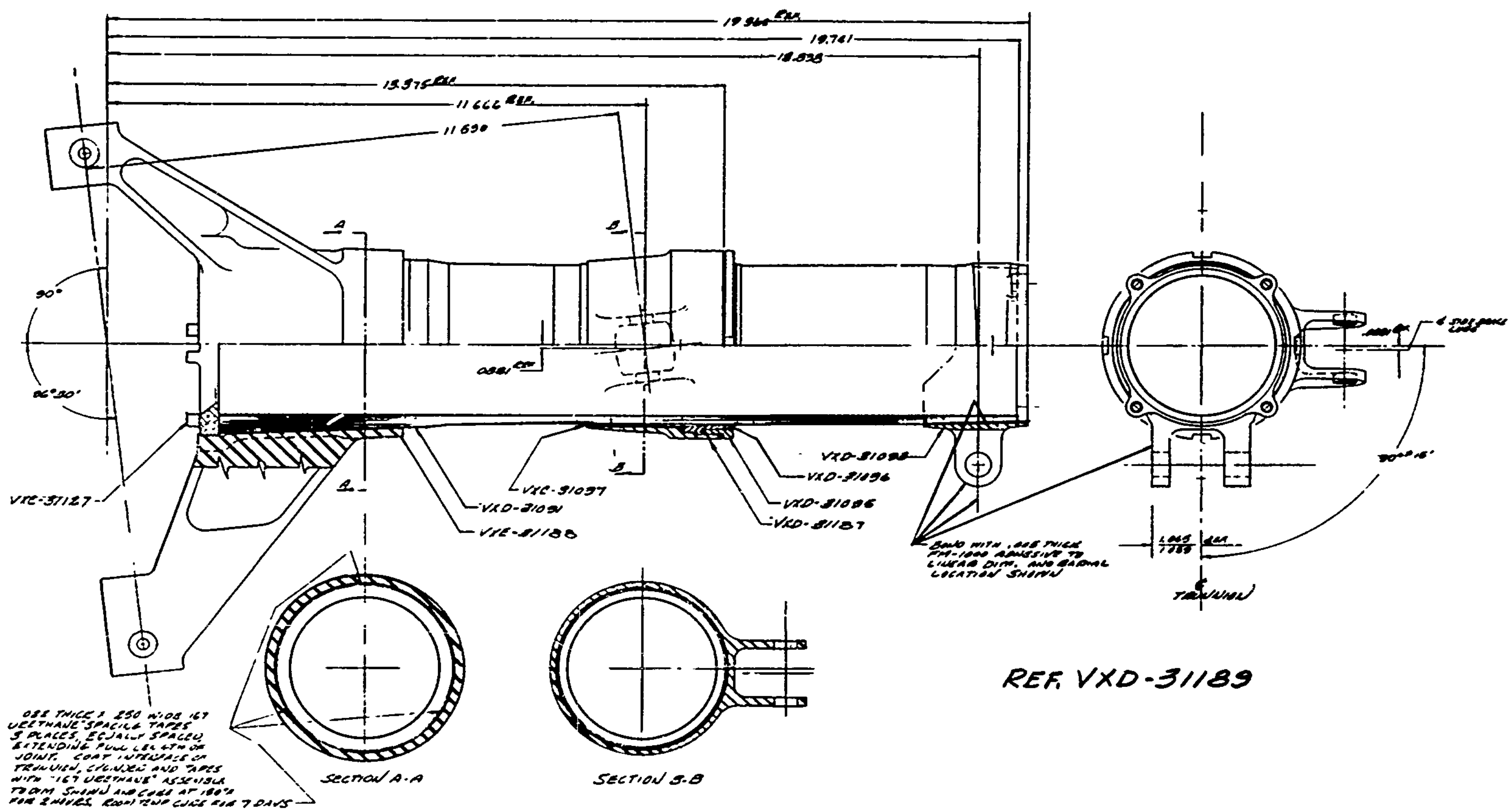


Figure 8-61. Outer Cylinder Prototype Assembly (Test Version)

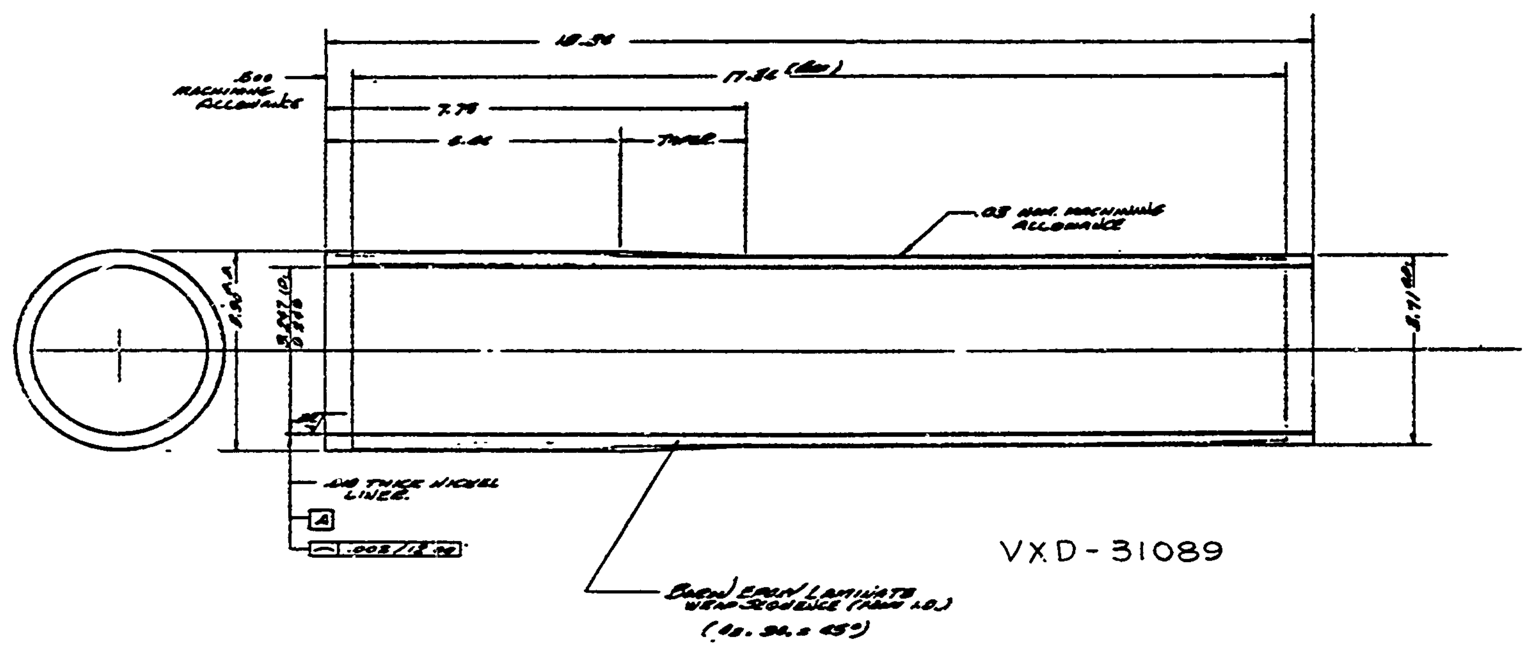


Figure 8-62. Boron-Epoxy Filament Composite Tube for Outer Cylinder Assembly

Figure 8-63. Nickel Plated Outer Cylinder Mandrel

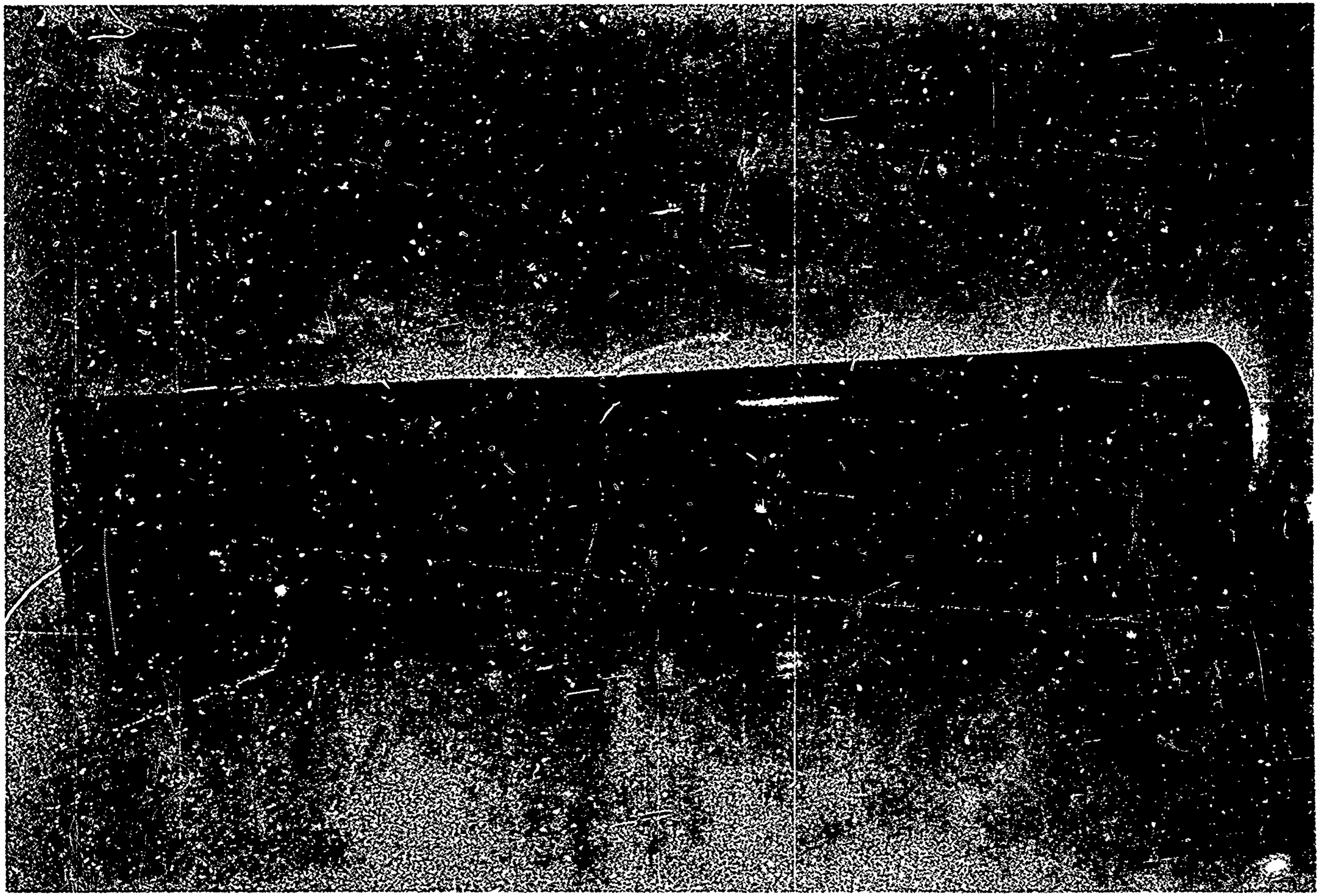


Figure 8-64. Outer Cylinder Before Machining (P-25150C)

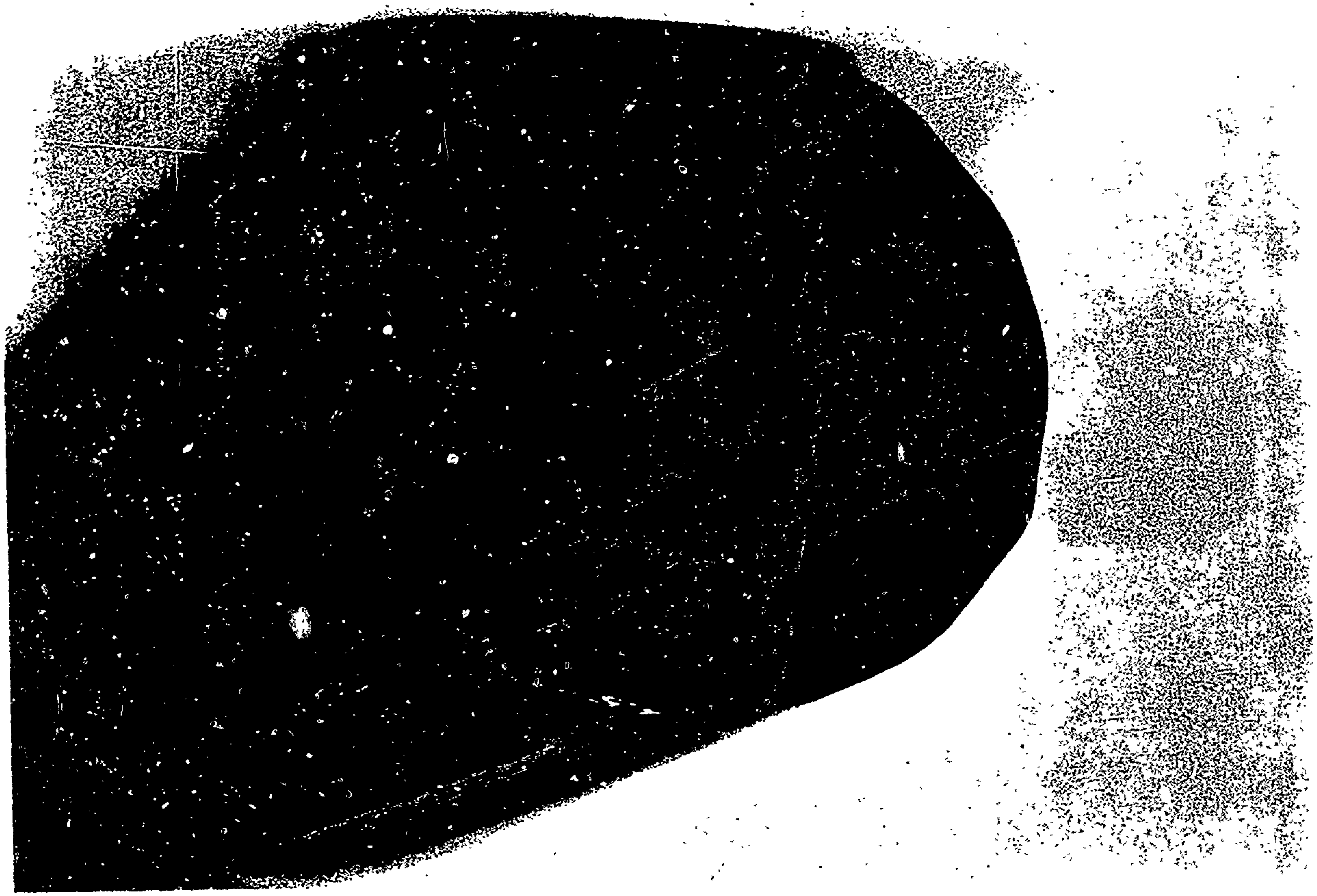


Figure 8-65. Outer Cylinder, Large End (P-25150B)

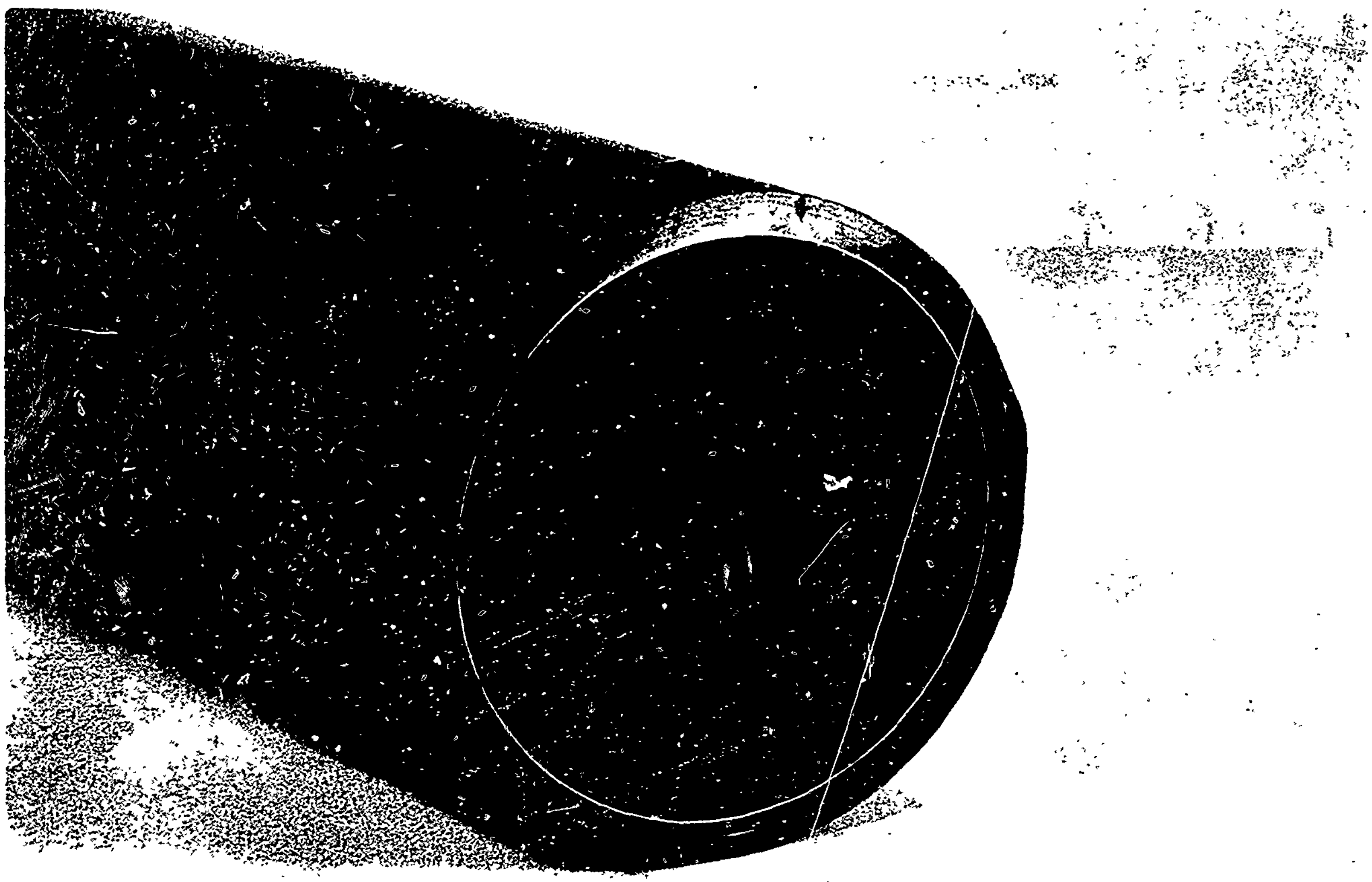


Figure 8-66. Outer Cylinder, Small End (P-25150A)

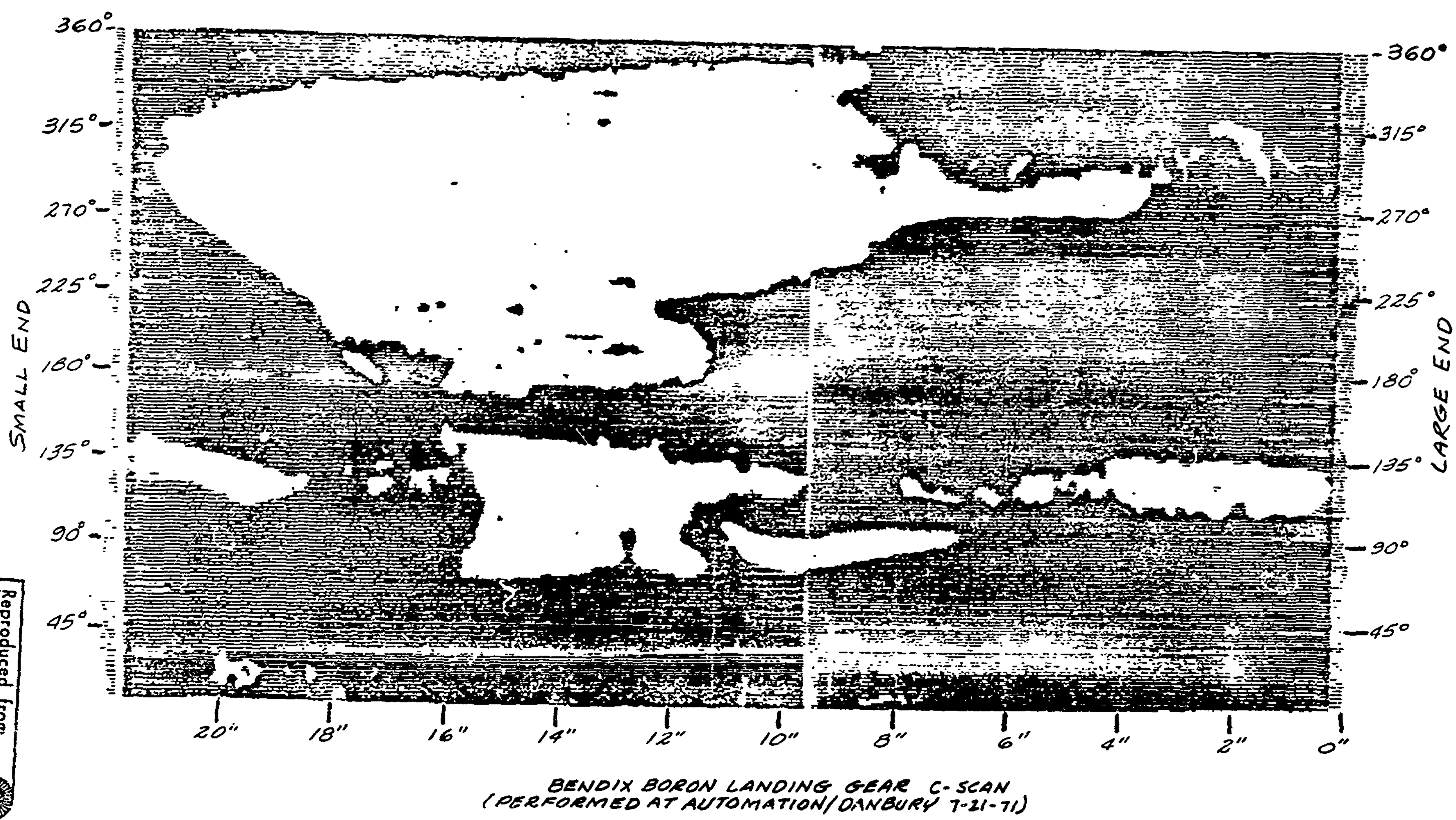


Figure 8-67. C-Scan Inspection, Prototype Outer Cylinder Tube

2. Bendix Activities (Prototype Outer Cylinder)

The fabrication effort applied by Bendix was performed in the following steps.

1. Fittings - Procured and inspected metal fittings shown in Figure 8-68.

2. Inspection - Received and inspected Hercules furnished boron filament tube, Figures 8-64 through 8-67. A number of delaminated regions were evident. The most severe separation appeared to be at the 90° - 135° region. Also it was determined that the inside of the cylinder was 0.013" out of round.

3. Grinding - Using a diamond grinding wheel the outside surface of the tube was ground to the dimensions shown in Figure 8-69. The resulting appearance of the cylinder is shown in Figures 8-70, 8-71 and 8-72. The delamination flow in the 90° -135° region is readily apparent.

4. Fiber Glass - Applied and machined the fiber glass reinforcements at the trunnion and side brace fittings in accordance with the instructions of Figure 8-73. The processing details were the same as applied to the 48 ply trail specimen, Paragraph 8.2.5.1 (Fittings - Second Design). The result of this operation is shown in Figure 8-74.

5. Trunnion Fitting - Assembled the trunnion fitting to the large end of the cylinder per Figure 8-61. Inserted the urethane cushion between the fitting and tube using the process detailed for the 48 ply trial specimen, Paragraph 8.2.5.1 (Urethane Application). Torque down retaining nut VXC-31127. The result is shown in Figure 8-75.

6. Side Brace Fitting - Assembled the side brace fittings as indicated in Paragraph 5.3.1.3. (2. Mechanical Joint Concept, Side Brace Attachment). All surfaces including the threads were coated with liquid urethane prior to assembly. The assembly was finally cured at 150°F. The final assembly is shown in Figures 8-76 and 8-77.

7. Torque Arm Fitting - The original intention was to bond this fitting to the cylinder by using FM-1000 adhesive which requires a 350°F cure. The process for bonding with this adhesive was developed during the Phase I trial specimen effort, Paragraph 8.2.5.1 (Ten Play Tube, Bonding Problems). However, there was concern that subjecting the tube to a high temperature cure might cause further propogation of the delamination flaws and additional distortion of the tube I.D. To avoid this possibility, a room temperature resin, Epon 934, was substituted. The joint was cured at room temperature for 7 days before loading.

   The resulting joint is illustrated in Figure 8-78.

Figure 8-68. Metallic Hardware for Outer Cylinder

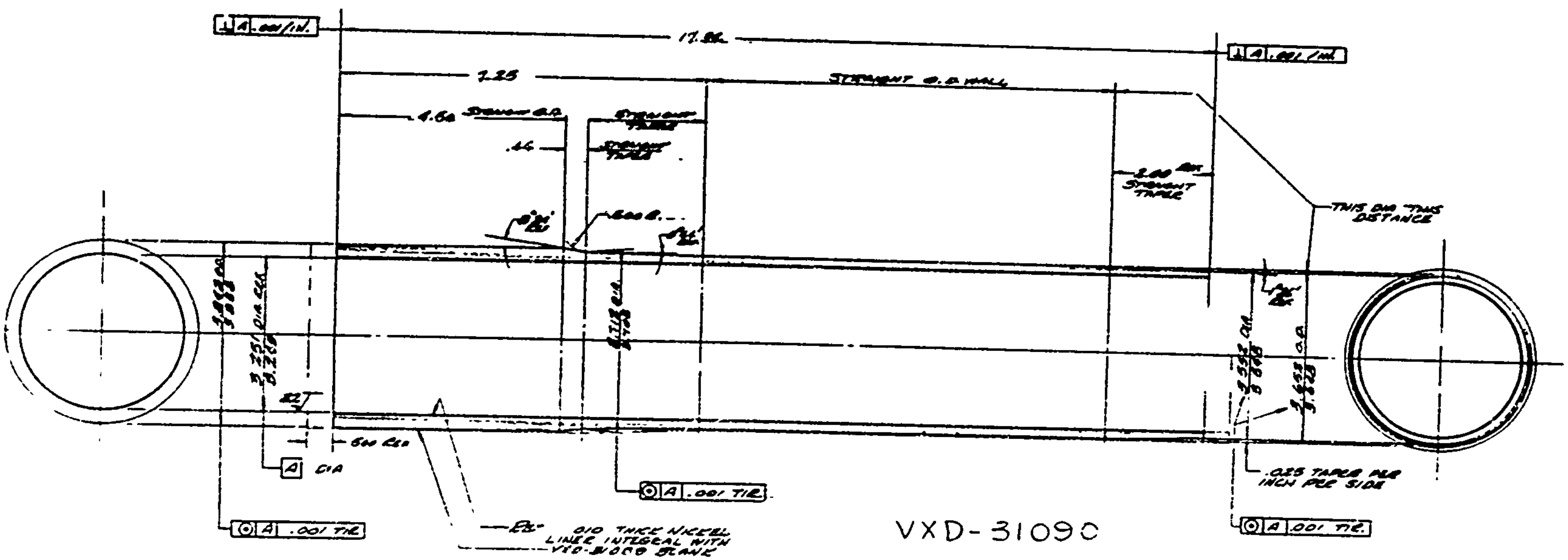


Figure 8-69. Boron-Epoxy Outer Cylinder Tube, Semi-finished

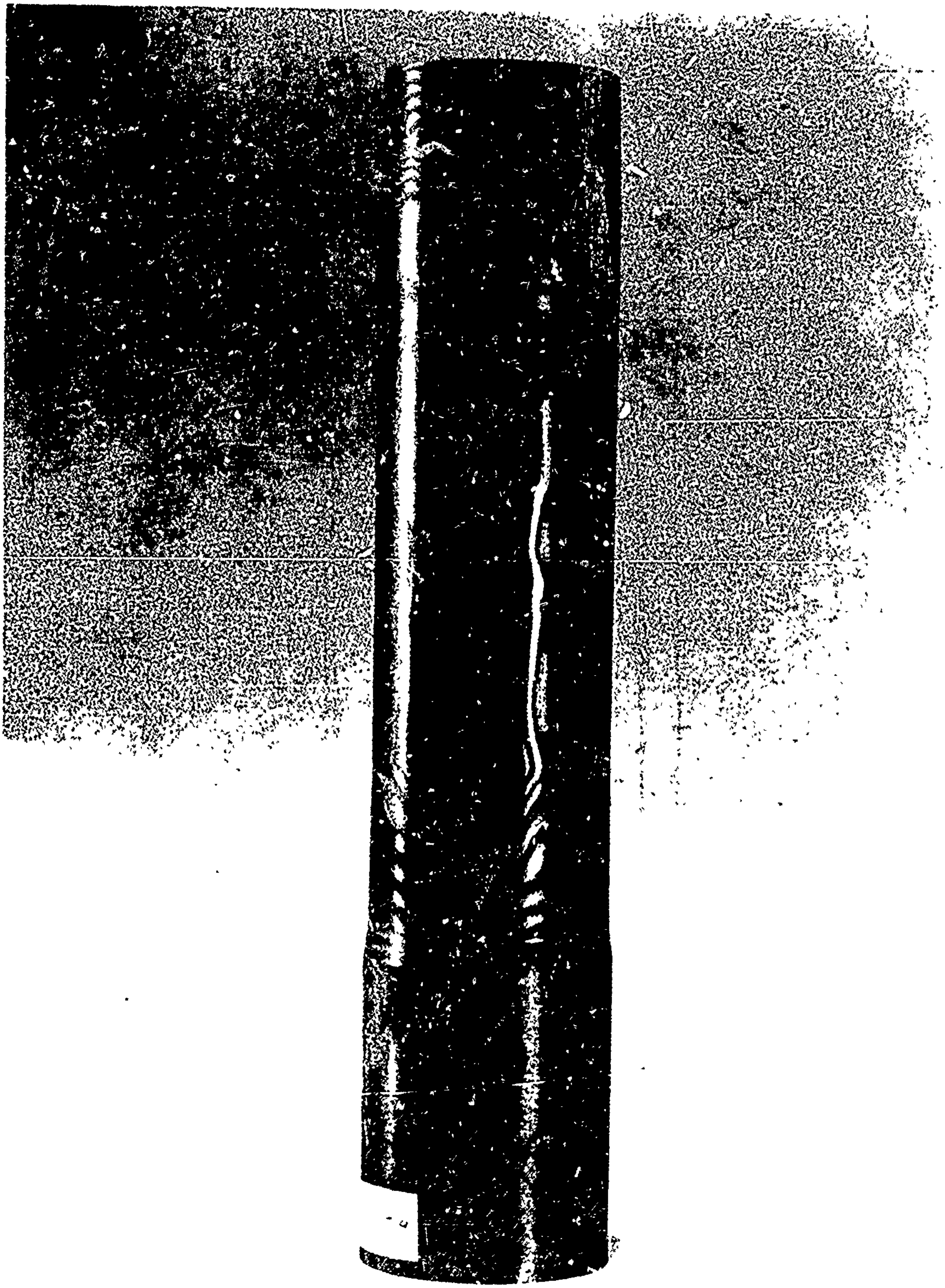


Figure 8-70. Ground Tube Showing 90°-135° Region (P-25150F)

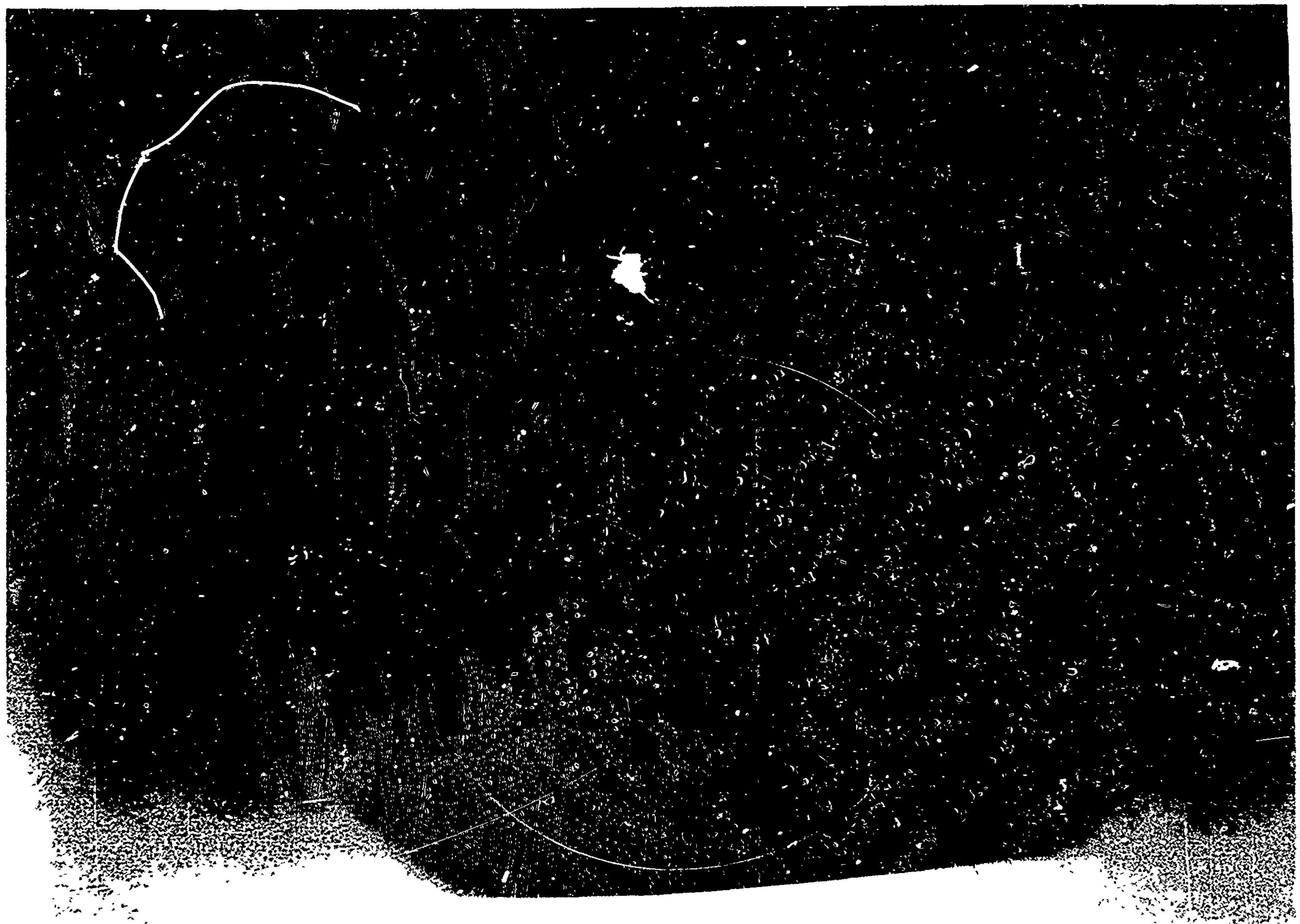


Figure 8-71. Tube End Showing Separation of 90° Position (P-25150D)

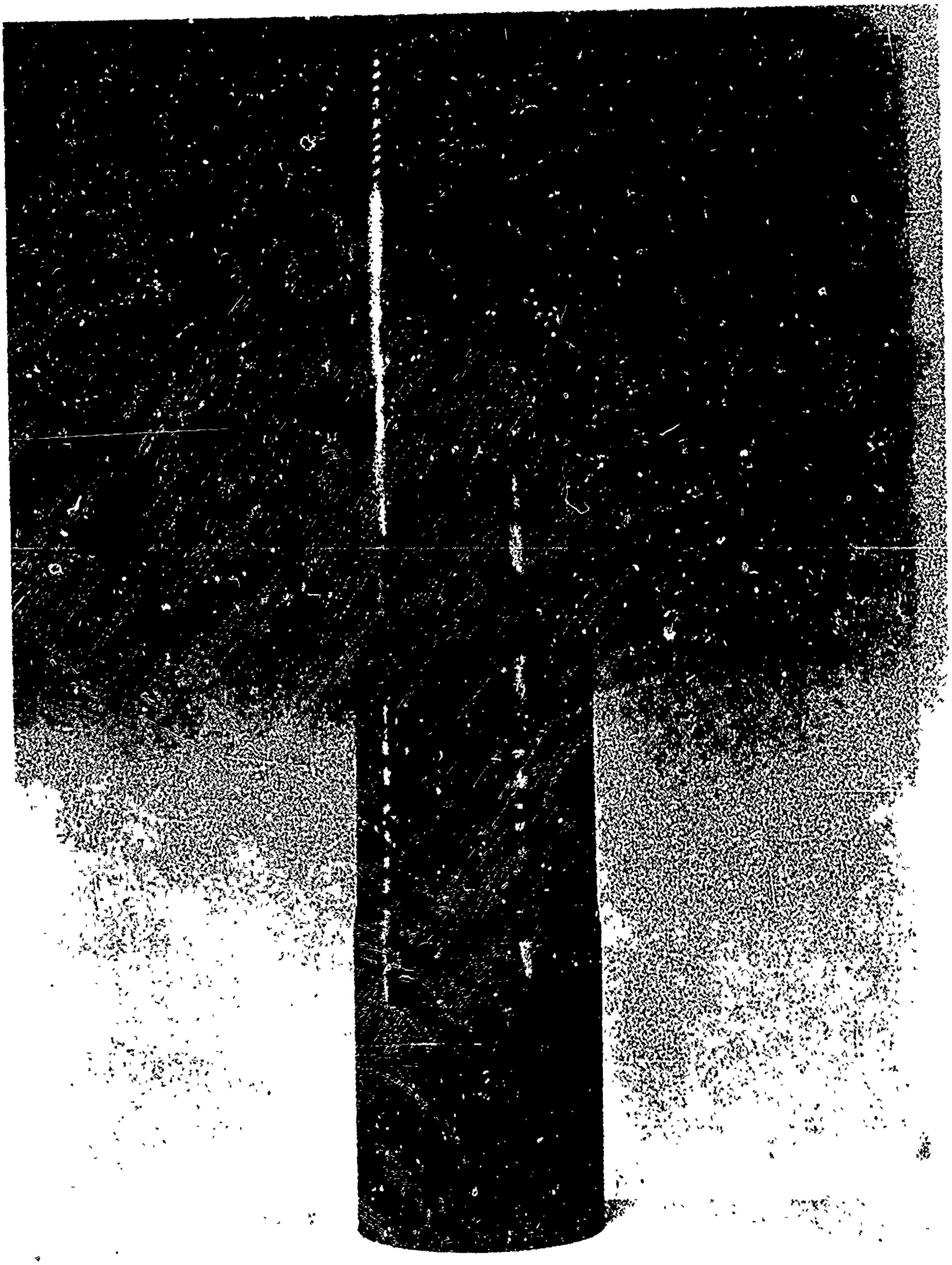


Figure 8-72. Ground Tube Showing 270° Region (P-25150E)

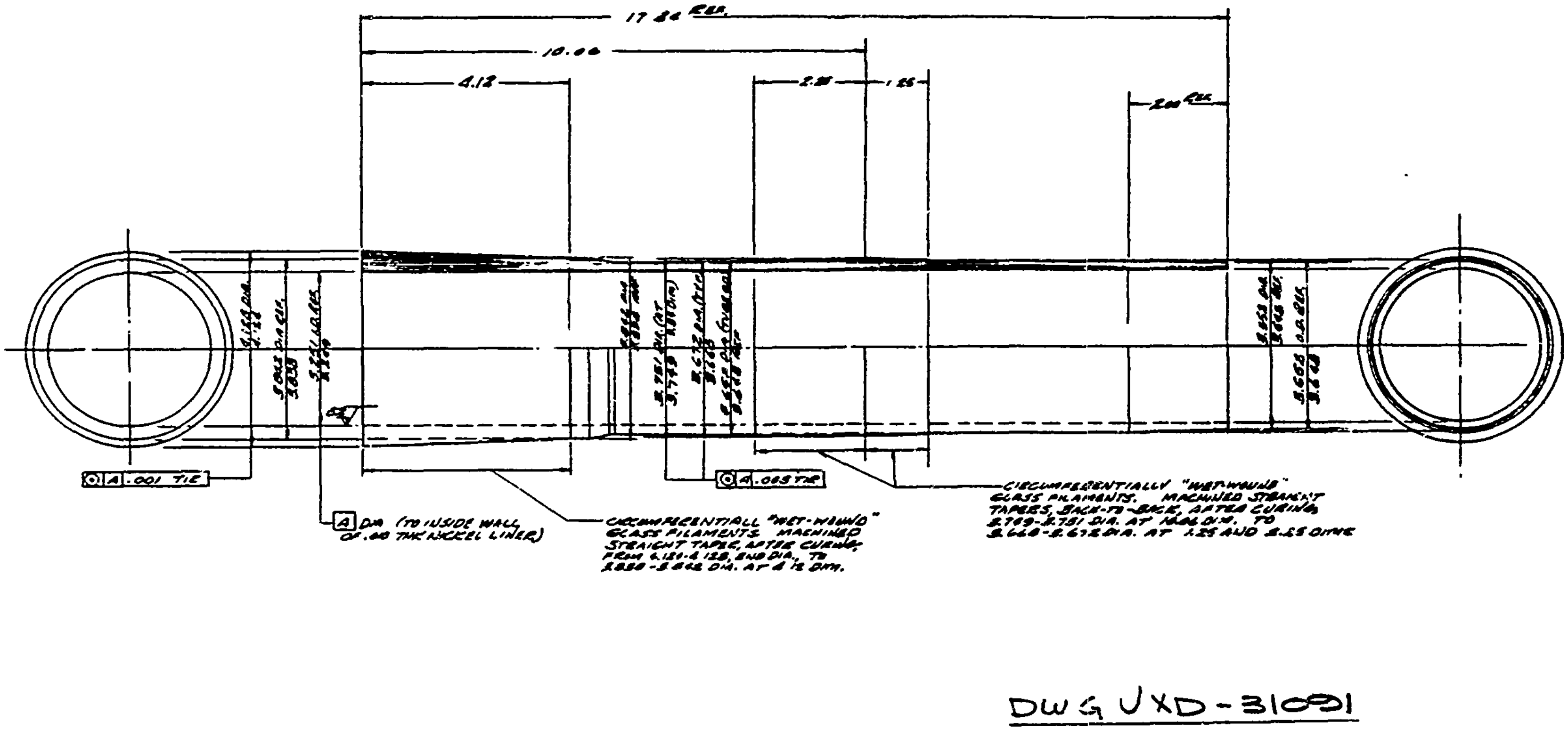


Figure 8-73. Boron-Epoxy Outer Cylinder Tube with Glass Reinforcements

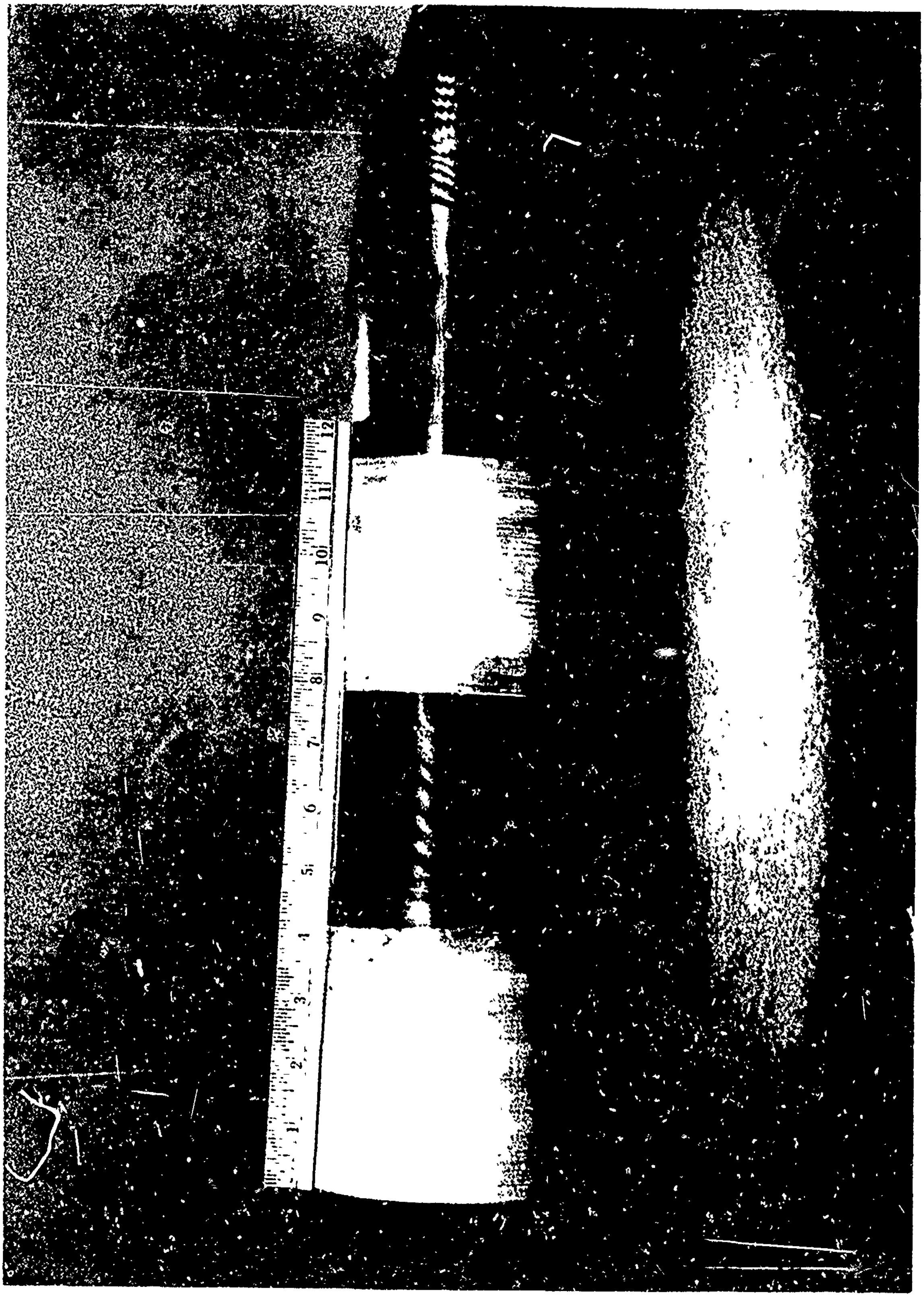


Figure 8-74. Outer Cylinder with Fiber Glass Overwrap (P-25150G)

Figure 8-75. Trunnion Socket Joint (P-25150L)

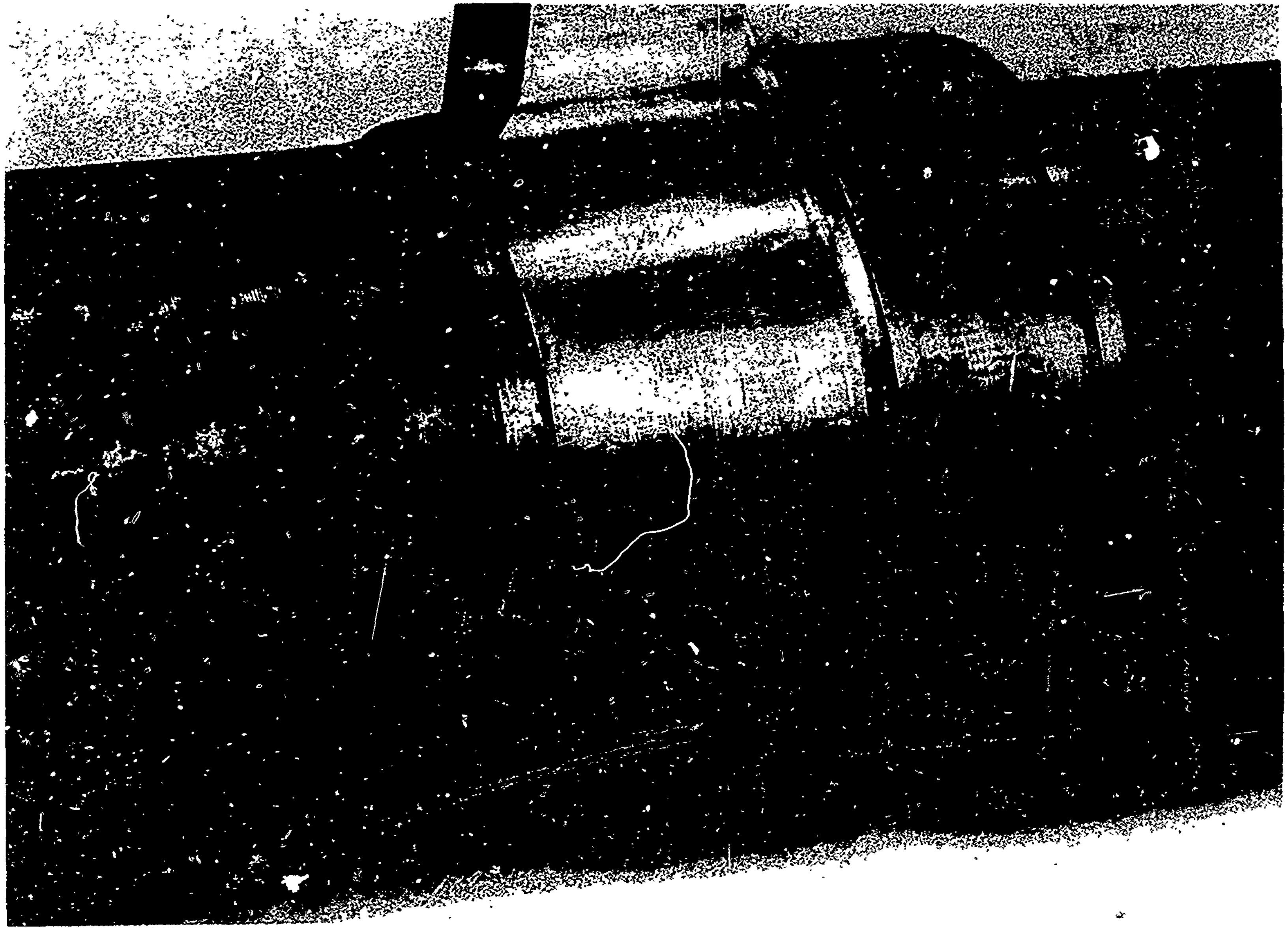


Figure 8-76. Assembled Side Brace Fitting (P-25150K)

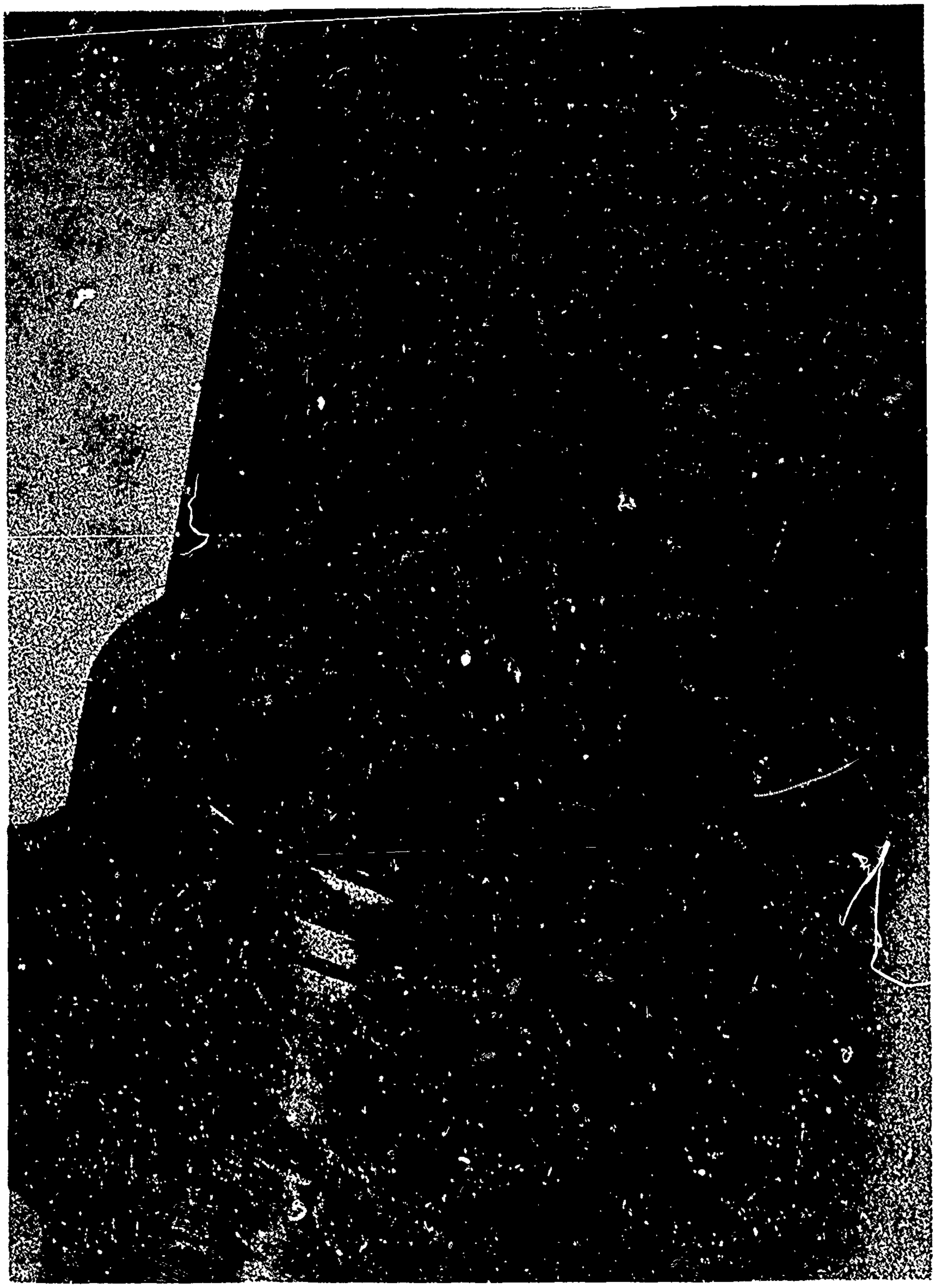


Figure 8-77. Assembled Side Brace Fittings (P-25150H)

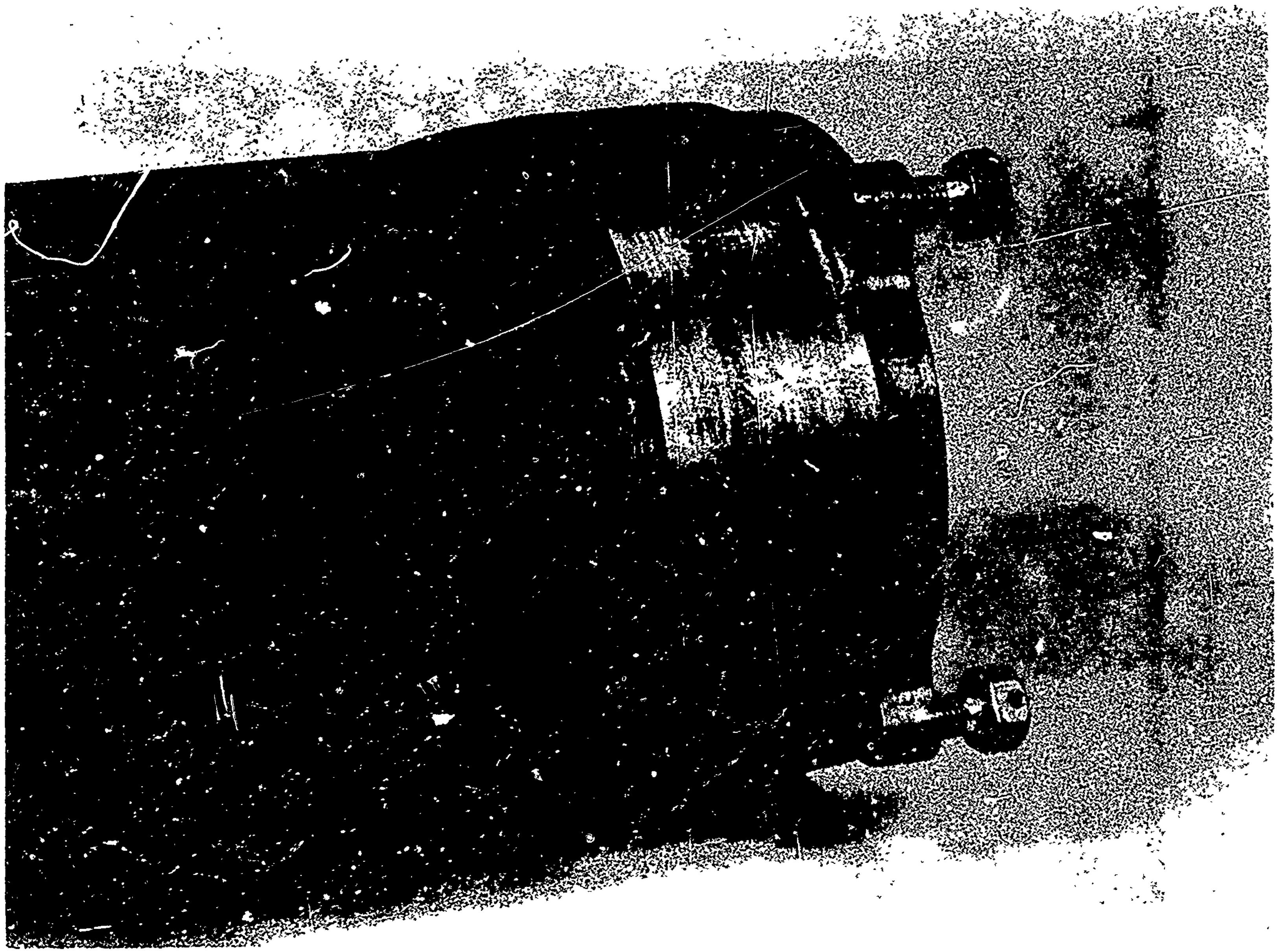


Figure 8-78. Torque Arm Fitting Joint (P-25150J)

8.2.6 Fabrication of the Boron-Epoxy Piston Cylinder Products

This section describes firstly the processing applied to the Phase I trial specimens and secondly that applied to the Phase II prototype piston.

8.2.6.1 Trial Specimen

This item is illustrated in Figure 8-79. The design details are discussed in Paragraph 5.

The boron epoxy tube was fabricated by Hercules. Bendix effort dealt with machining of the composite cylinder, fabrication of the metallic fittings and assembly of all parts into the final piston-axle specimen assembly.

1. Hercules Activities.

The Hercules effort consisted of fabrication of the cylinder illustrated in Figure 8-80.

Fabrication Details VXD-31048

Materials

Boron BP-907 broadgoods (2002B).

Teflon coated glass scrim (TX-1040)
Pallflex Products Corporation, Kennedy Drive, Putnam, Conn.

Teflon coated glass cloth (Armalon 95-604)
E.I. duPont, Industrial Fabric Sales, Wilmington, Delaware

Boron filaments - Hamilton Standard

Sheet resin (BP907-104A - 0.020 lbs/ft^2)
American Cyanamid Company

Liquid resin (BP-907) - American Cyanamid Company

Mold release (Frekote 33)
Frekote Inc., 2300 N. Emerson Avenue, Indianapolis, Indiana

Vacuum bag (0.002" nylon film)

Teflon shrink tubing (3" dia.)
American Durafilm Company, Inc., 2300 Washington St., Newton Lower Falls, Mass.

Preparation

An aluminum mandrel was fabricated in lathe according to print dimension, allowing for expansion during cure.

Frekote mandrel.

Mandrel installed in lathe.

Fabrication of Tube

1.(A) Mandrel covered with a sheet of BP-907 resin paper.

(B) Boron set up and run through Alpha-primer and heated same as in winding broadgoods. Machine set on 108 turns/in. First layer wound with two filaments boron.

(C) Two 0^{o} mats installed over 90^{o} wind. At point where diameters are different, material was cut so as to remove buckle.

2.(A) One ply of coarse Armalon applied. Glass roving wound (27 TPI) over Armalon using a torque motor and using 60% torque (8 lbs tension).

NOTE: This yields approximately 150 psi consolidation pressure.

(B) Heat applied using heat gun. Part heated to approximately $180^{o}F$.

(C) Let cool to room temperature.

(D) Remove roving and Armalon.

3. Repeat Step 1.(C). Apply two plies 0^{o} orientation.

4. Repeat Step 2. Compact.

5. Wind 90^{o} layer. Use heat gun to make resin tacky.

6.(A) A plus 45^{o} and a minus 45^{o} layer applied holding specified distances from Ref. line (see ply cutting and Reference table).

NOTE: In some instances broadgoods had to be cut and removed to relieve buckle in material and some places gaps had to be filled in.

(B) One ply of coarse Armalon applied to tapered end (45° mats only). Glass roving wound over Armalon using 60% torque.

(C) Heat applied using heat gun. Part heated to approximately 180°.

(D) Let cool to room temperature.

(E) Removed roving and Armalon.

7. Repeat Section 6.

8. Repeat Section 6.

9.(A) Repeat Section 1.(C). (Apply two layers 0° prepreg)

(B) Repeat Section 2. (Compact)

10.(A) Repeat Section 1.(C). (Apply two layers 0° prepreg)

(B) Repeat Section 2. (Compact)

11. Repeat Section 5. (Wind 90° ply)

12.(A) A $+45^\circ$, -45° and a $+45^\circ$ mat applied holding specified distances from Ref. line. (Reference Note in 6.(A).)

(B) Repeat Section 6.(B), (C), (D), and (E). (Compact)

13. Repeat Section 12. (-45°, $+45^\circ$, -45° and Compact)

14.(A) Repeat Section 1.(C). (2 plies 0°)

(B) Repeat Section 2. (Compact)

15.(A) Repeat Section 1.(C). (2 plies 0°)

(B) Repeat Section 2. (Compact)

16. Repeat Section 5. (Wind 90° ply)

17. Repeat Section 6. (+45, -45, Compact)

18. Repeat Section 6. (+45, -45, Compact)

19. Repeat Section 6.

20.(A) Four 0° mats were installed over entire length of part. Ref. to Note in 6.(A).

(B) Repeat Section 2. (Compact)

21. Repeat Section 6. (Wind 90°)

22. Repeat Section 12. (+45, -45, +45, Compact)

23. Repeat Section 12. (-45, +45, -45, Compact)

24. Repeat Section 20. (4 plies 0°, Compact)

25. Repeat Section 5. (Wind 90°)

26. Repeat Section 12. (+45, -45, +45, Compact)

27. Repeat Section 12. (-45, +45, -45, Compact)

28. Repeat Section 20. (4 plies 0°, Compact)

29. Repeat Section 5. (Wind 90°)

30. Repeat Section 12. (+45, -45, +45, Compact)

31. Repeat Section 12. (-45, +45, -45, Compact)

32.(A) Repeat Section 1.(C). (2 plies 0°)

(B) Repeat Section 2. (Compact)

33.(A) Repeat Section 1.(C). (2 plies 0°)

(B) Repeat Section 2. (Compact)

34. Repeat Section 5. (Wind 90°)

35. Repeat Section 12. (+45, -45, +45, Compact)

36. Repeat Section 12. (-45, +45, -45, Compact)

37. Repeat Section 20. (4 plies 0°, Compact)

38. Repeat Section 5. (Wind 90°)

39. Repeat Section 12. (+45, -45, +45, Compact)

40. Repeat Section 12. (-45, +45, -45, Compact)

41.(A) Repeat Section 1.(C) (2 Plies 0°)

(B) Repeat Section 2. (Compact)

42.(A) Repeat Section 1.(C) (2 Plies 0°)

(B) Repeat Section 2. (Compact)

43. Repeat Section 5. (Wind 90°)

44. Repeat Section 12. (+45, -45, +45, Compact)

45. Repeat Section 12. (-45, +45, -45, Compact)

46. Repeat Section 20. (4 plies 0°, Compact)

47. Repeat Section 5. (Wind 90°)

48. Repeat Section 12. (+45, -45, +45, Compact)

49. Repeat Section 12. (-45, +45, -45, Compact)

50.(A) Repeat Section 1.(C). (2 plies 0°)

(B) Repeat Section 2. (Compact)

51.(A) Repeat Section 1.(C). (2 plies 0°)

(B) Repeat Section 2. (Compact)

52. Repeat Step 5. Last layer of 90°.

<u>Cure</u>

A.(1) A layer of BP-907 resin paper attached over last 90° wind.

(2) Two pieces of teflon coated scrim TX-1040 and three pieces of coarse Armalon installed.

(3) Glass roving wound over Armalon with 60% torque.

(4) Part heated to approximately 180°.

(5) Let cool to room temperature.

(6) Glass and Armalon removed.

B. Install shrink tubing as per insturctions.

C.(1) Installed in vacuum bag.

(2) Installed thermocouple.

D.(1) Cured in autoclave: ½ hour at 180°
½ hour at 280°
1 hour at 350°

(2) Cooled down under pressure.

(3) Removed from autoclave.

(4) Removed vacuum bag, thermocouple wire and shrink tubing.

E. Machined to length per drawing dimensions.

Ply Cutting and Reference Table

Ply Number	Orientation	Distance from Reference
1	90	L*
2	0	L
3	0	L
4	0	L
5	0	L
6	90	L
7	+45	.167
8	-45	.333
9	+45	.500
10	-45	.667
11	+45	.833
12	-45	1.000
13	0	L
14	0	L
15	0	L
16	0	L
17	90	L
18	+45	.083
19	-45	.250
20	+45	.416
21	-45	.583
22	+45	.750
23	-45	.916
24	0	L
25	0	L
26	0	L
27	0	L
28	90	L
29	+45	.125
30	-45	.292
31	+45	.458
32	-45	.625
33	+45	.792
34	-45	.958
35	0	L
36	0	L
37	0	L
38	0	L
39	90	L
40	+45	.042
41	-45	.208
42	+45	.375
43	-45	.542
44	+45	.709
45	-45	.875
46	0	L
47	0	L
48	0	L
49	0	L
50	90	L

*total length of tube

Ply Number	Orientation	Distance from Reference
51	+45	2.087
52	-45	2.493
53	+45	2.900
54	-45	3.307
55	+45	3.713
56	-45	4.120
57	0	L
58	0	L
59	0	L
60	0	L
61	90	L
62	+45	1.951
63	-45	2.358
64	+45	2.764
65	-45	3.171
66	+45	3.578
67	-45	3.984
68	0	L
69	0	L
70	0	L
71	0	L
72	90	L
73	+45	1.816
74	-45	2.222
75	+45	2.629
76	-45	3.036
77	+45	3.442
78	-45	3.849
79	0	L
80	0	L
81	0	L
82	0	L
83	90	L
84	+45	2.019
85	-45	2.426
86	+45	2.832
87	-45	3.239
88	+45	3.645
89	-45	4.052
90	0	L
91	0	L
92	0	L
93	0	L
94	90	L
95	+45	1.883
96	-45	2.290
97	+45	2.697
98	-45	3.103
99	+45	3.510
100	-45	3.917

Ply Number	Orientation	Distance from Reference
101	0	L
102	0	L
103	0	L
104	0	L
105	90	L
106	+45	1.748
107	-45	2.154
108	+45	2.561
109	-45	2.968
110	+45	3.374
111	-45	3.781
112	0	L
113	0	L
114	0	L
115	0	L
116	90	L

2. Bendix Activities (Trial Specimen - Piston)

The fabrication effort applied by Bendix occurred in the following steps.

1. Inspection - The rough composite tube was received from Hercules. By visual inspection the ID of the tube appeared excellent. However, on the outside surface a slight longitudinal bulge was evident along the length of the tube and the outer 90° ply appeared distorted.

2. Grinding - The tube was cut to length and ground to final outside dimensions in accordance with Figure 8-80. Cutting and grinding were done with a 6-inch diameter diamond wheel. Wheel tip speed was 3000 fpm and water was applied as the coolant.

Examination of the trimmed tube revealed several interlaminar voids, Figures 8-81 and 8-82. It is believed that this occurred because of insufficient compaction prior to winding the 90° plies.

3. Fittings - The metallic fittings were machined by Bendix.

4. Assembly - Figure 8-79 - The composite piston cylinder was assembled to the simulated axle by the identical process used to attach the trunnion end fitting to the outer cylinder trial specimen (Paragraph 8.2.5.1, 48 ply, Second Design, Urethane Application). After the urethane had cured seven days, the threaded plug was applied with a 400 ft.-lb. torque. A graphite type antiseize compound was used on the threads prior to assembly.

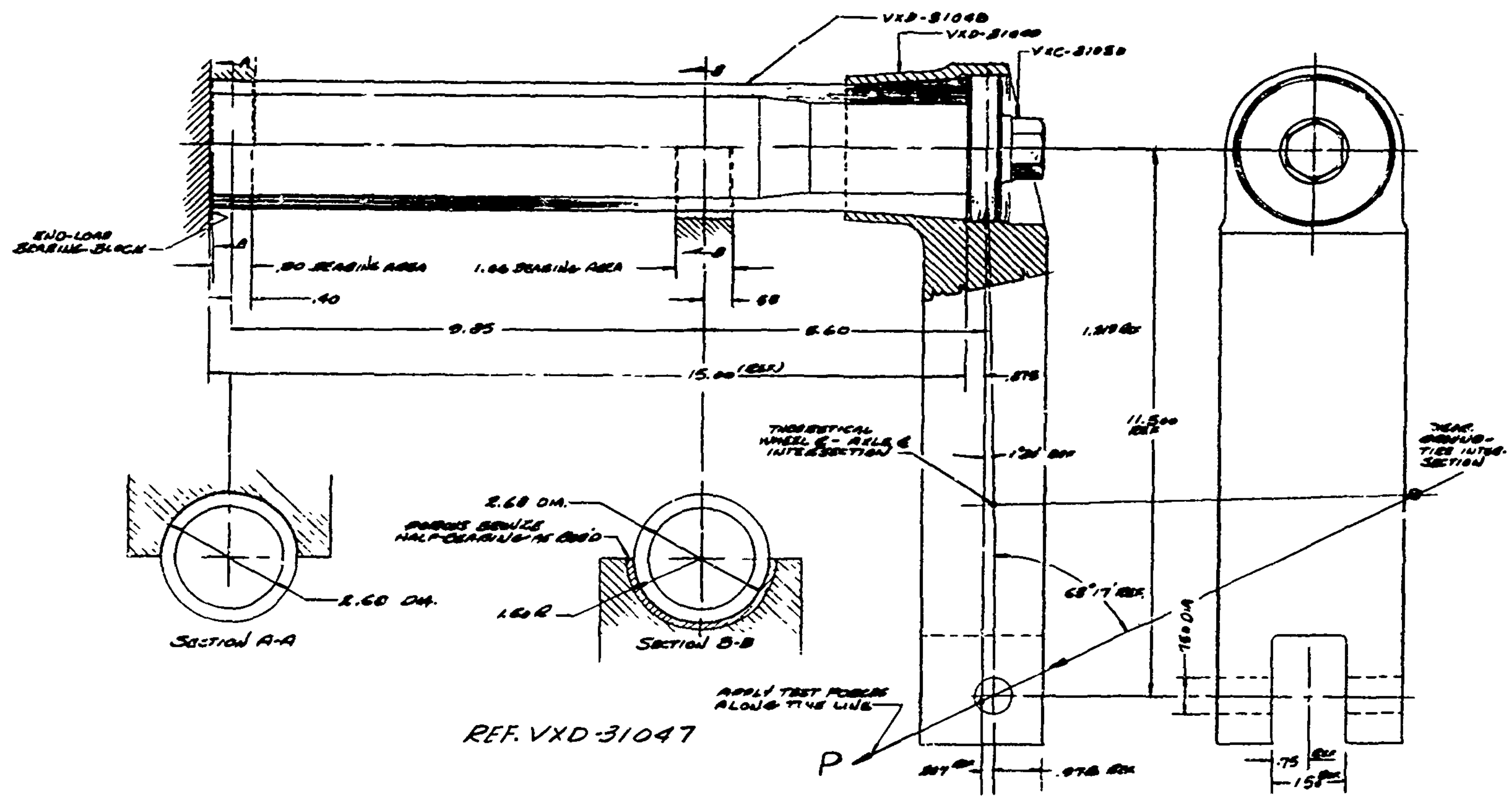


Figure 8-79. Boron-Epoxy Piston Specimen

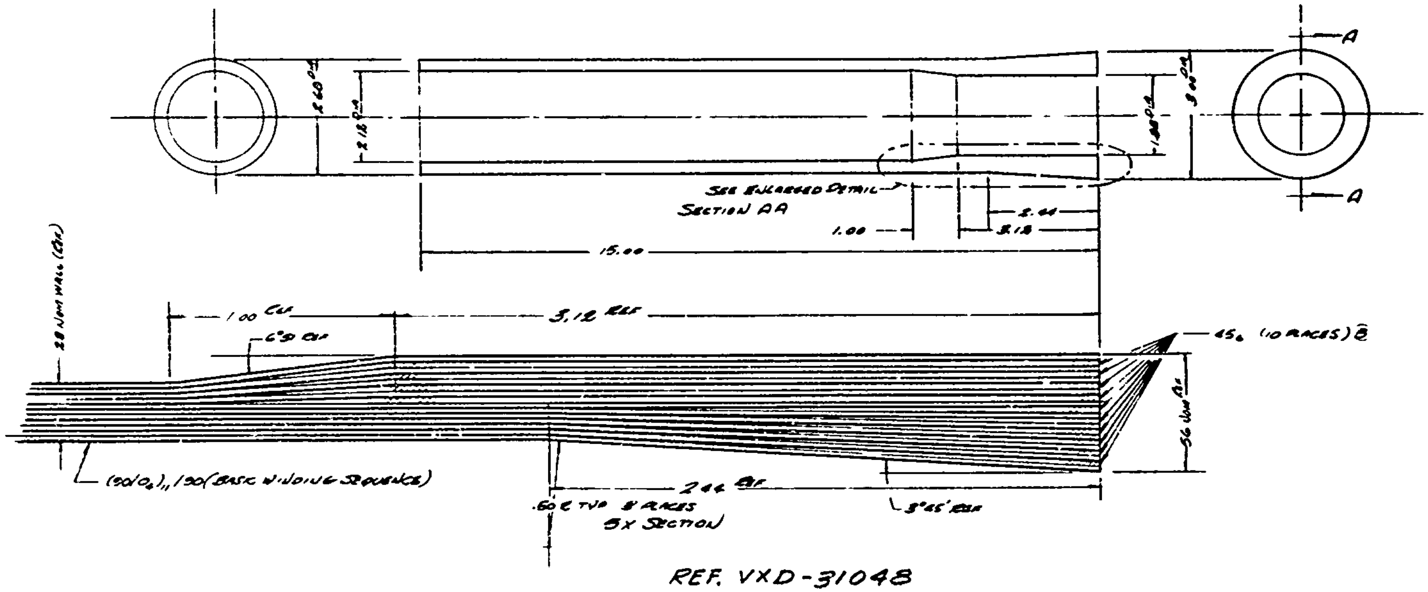


Figure 8-80. Cylinder for Boron-Epoxy Piston Specimen

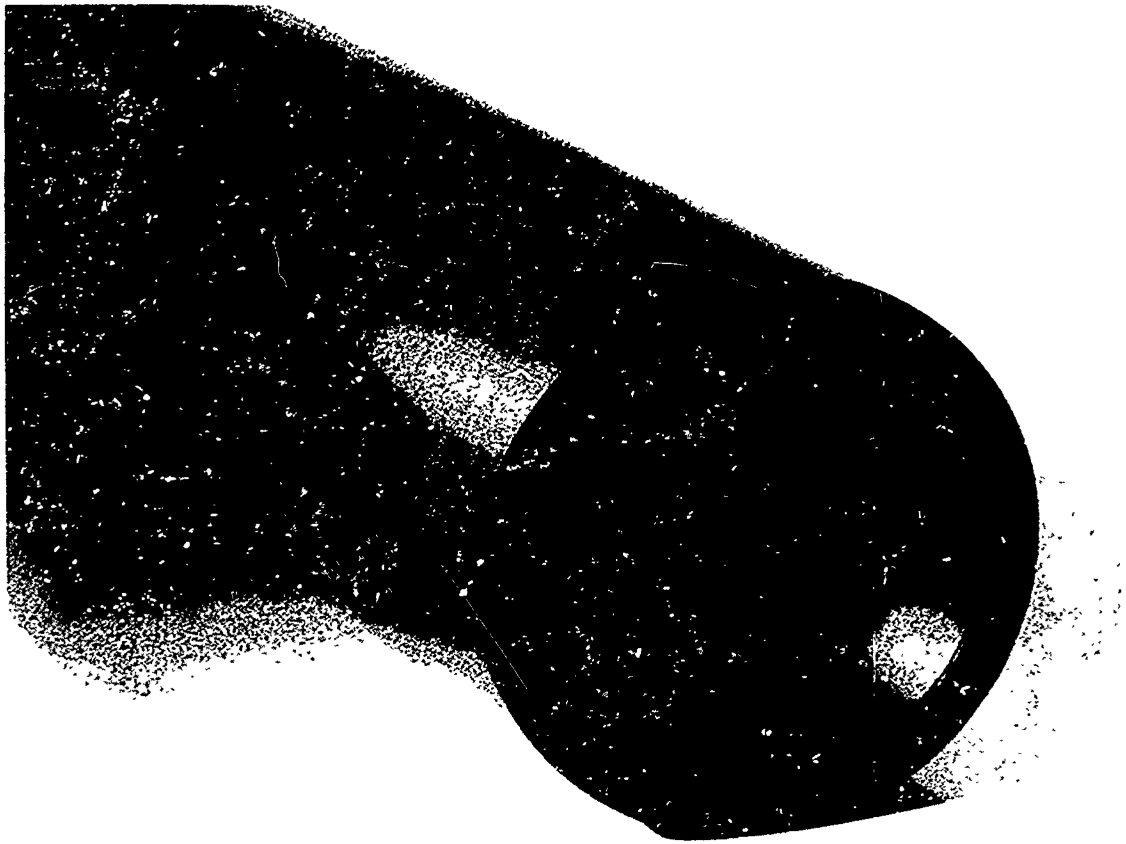


Figure 8-81. End View of Boron-Epoxy Piston Cylinder

Figure 8-82. End View of Boron-Epoxy Piston Cylinder

8.2.6.2 Fabrication of the Boron-Epoxy Prototype Piston-Axle Assembly

This item is illustrated in Figure 5-90. The design details are discussed in Paragraphs 5.3.1.4 and 6.4.

The boron-epoxy cylinder was fabricated by Hercules. Bendix effort dealt with machining of the composite cylinder, procurement of conventional metallic fittings and assembly of all parts into the final piston-axle assembly.

1. Hercules Activities

The Hercules effort consisted of fabrication of the cylinder illustrated in Figure 8-83.

Fabrication Process for Piston Cylinder VXD-31098

1. Prepare aluminum mandrel for nickel plating.
2. Cast salt mandrel.
3. Machine salt mandrel.
4. Electroplate aluminum mandrel.
5. Assemble and prepare mandrel for winding.
    a. Measure and record diameters and TIR.
    b. Clean and FreKote salt and aluminum portion of mandrel.
    c. Sandblast nickel surface and prepare for bonding.
    d. Assemble mandrel.
6. Fabricate broadgoods - 90 ft^2.
7. Apply lamina for internal holder.
    a. Apply sheet of resin paper over nickel surface with Armalon and nylon to protect surface.
    b. Apply one sheet of resin paper 0.580" x 5.50".
    c. Apply two 0^{o} plies:
        (1) 1st ply 0.580" x 5.50"
        (2) 2nd ply 0.588" x 5.53"
    d. Consolidate:
        (1) Apply Armalon.
        (2) Apply Vacuum bag.
        (3) Heat surface.
        (4) Overwrap with glass.

(5) Cool to RT.
(6) Remove glass.
(7) Remove vacuum bag.
(8) Clean surface with triclean to remove any foreign particles.

e. Apply two 90° wraps (heat surface while winding).

f. Record minimum and maximum diameter.

g. Determine width and length of 0° plies as follows:

(1) Average the diameter of last 90° ply.
(2) Subtract 1.750" from this diameter.
(3) Call the difference "X".
(4) Add 0.580 to "X" and call the answer "L".
(5) "L" is the length (in the fiber direction) of the 0° ply.
(6) Multiply the average diameter (Step 1) by pi and call this answer "W".
(7) "W" is the width (perpendicular to fiber direction) of the 0° ply.

h. Apply two 0° plies - determine size per Step "g".

i. Consolidate per Step "d".

j. Apply two 90° wraps (heat surface while winding).

k. Record minimum and maximum diameter.

l. Apply two 0° plies - determine size per Step "g".

m. Consolidate per Step "d".

n. Apply two 90° wraps (heat surface while winding).

o. Record minimum and maximum diameter.

p. Apply two 0° plies - determine size per Step "g".

q. Consolidate per Step "d".

r. Apply two 90° wrap (heat surface while winding).

s. Record minimum and maximum diameter.

t. Apply two 0° plies - determine size per Step "g".

u. Consolidate per Step "d".

v. Apply two 90° wraps (heat surface while winding).

w. Record minimum and maximum diameter.

x. Apply two 0° plies - determine size per Step "g".

y. Consolidate per Step "d".

z. Apply two 90^{o} wraps (heat surface while winding).

aa. Record minimum and maximum diameter.

ab. Apply two 0^{o} plies - determine size per Step "g".

ac. Consolidate per Step "d".

ad. Apply two 90^{o} wraps (heat surface while winding).

ae. Record minimum and maximum diameter.

.
.
.
.
.

etc.

Repeat this sequence until the plies are even with the surrounding mandrel 42 plies.

NOTE: Salt mandrel was unable to withstand environment caused by fabricating internal holder. The salt mandrel was replaced with an aluminum mandrel for winding purpose. After winding, however, the salt mandrel was used as originally intended.

8. Remove nylon, Armalon and resin from nickel surface.

9. Apply lamina for main tube body.

a. Apply layer of sheet resin to entire surface 22.3" long.

b. Apply two 0^{o} plies to entire length of mandrel.

NOTE: Plies will be cut to fit at taper end of mandrel.

c. Consolidate per Step "7d".

d. Measure and record minimum and maximum diameter at 3 locations along the tube.

e. Apply $\pm 45^{o}$ plies 9.4" long, from nickel liner end.

f. Apply two 0^{o} plies from the edge of the $\pm 45^{o}$ plies continuing to the end of the tube (12.9" long).

g. Consolidate.

h. Measure and record minimum and maximum diameter at 3 locations.

i. Wind 90^{o} ply

j. Apply plies A1, A2, and A3 per Table 8-4.

k. Consolidate over taper.

l. Apply plies A4, A5, and A6 per Table 8-4.

m. Consolidate over taper.

n. Measure and record minimum and maximum diameter at taper end of tube.

o. Apply two 0^{o} plies 22.3" long.

p. Consolidate.

q. Measure and record minimum and maximum diameter at 3 locations.

r. Apply $\pm 45^{o}$ ply 13.4" long from nickel liner end.

s. Apply two 0^{o} plies (8.9" long) from the edge of the $\pm 45^{o}$ plies continuing to the end of the tube.

t. Consolidate.

u. Measure and record minimum and maximum diameter at 3 locations.

v. Wind 90^{o} ply - apply heat while winding.

w. Apply plies B1, B2, and B3 per Table 8-4.

x. Consolidate over taper.

y. Apply plies B4, B5, and B6 per Table 8-4.

z. Consolidate over taper.

aa. Measure and record Min. and Max. diameter at taper end of tube.

ab. Apply two plies 0°, 22.3" long.

ac. Consolidate.

ad. Measure and record Min. and Max. diameter at three locations.

ae. Apply ±45° ply 11.4" long from nickel liner end.

af. Apply two 0° plies 10.9" long from the edge of the ±45° plies continuing to the end of the tube.

ag. Consolidate.

ah. Measure and record Min. and Max. diameter at three locations.

ai. Wind 90° ply - apply heat while winding.

aj. Apply plies C1, C2, and C3 per Table 8-4.

ak. Consolidate over taper.

al. Apply plies C4, C5, and C6 per Table 8-4.

am. Consolidate over taper.

an. Measure and record Min. and Max. diameter at taper end of tube.

ao. Apply two plies 0°, 22.3" long.

ap. Consolidate.

aq. Measure and record Min. and Max. diameter at three locations.

ar. Apply ±45° ply 15.4° long from nickel liner end.

as. Apply two 0° plies 6.9" long from the edge of the ±45° plies continuing to the end of the tube.

at. Consolidate.

au. Measure and record Min. and Max. diameter at three locations.

av. Wind 90° ply - apply heat while winding.

aw. Apply plies D1, D2, and D3 per Table 8-4.

ax. Consolidate over taper.

ay. Apply plies D4, D5, and D6 per Table 8-4.

az. Consolidate over taper.

ba. Measure and record Min. and Max. diameter at taper end of tube.

bb. Apply two 0° plies 22.3" long.

bc. Consolidate.

bd. Apply two 0° plies 22.3" long.

be. Consolidate.

bf. Measure and record Min. and Max. diameter at three locations.

bg. Wind 90° ply - apply heat while winding.

bh. Apply plies E1, E2, and E3 per Table 8-4.

bi. Consolidate over taper.

bj. Apply plies E4, E5, and E6 per Table 8-4.

bk. Consolidate over taper.

bl. Measure and record Min. and Max. diameter at taper end of tube.

bm. Apply two 0° plies 13.3" long from tapered end.

bn. Consolidate.

bo. Apply two 0° plies 18.3" long from tapered end.

bp. Consolidate.

bq. Measure and record Min. and Max. diameter at three locations.

br. Apply 90° ply over 0° plies - blend into last 90° plies.

bs. Apply plies F1, F2, and F3 per Table 8-5.

bt. Consolidate.

bu. Apply plies F4, F5, and F6 per Table 8-5.

bv. Consolidate.

bw. Measure and record Min. and Max. diameter at taper end of tube.

bx. Apply two 0° plies 17.9" long from tapered end of tube.

by. Consolidate.

bz. Apply two 0° plies 17.9" long from tapered end of tube.

ca. Consolidate.

cb. Measure and record Min. and Max. diameter at three locations.

cc. Apply 90° ply over 0° plies - blend into last 90° ply.

cd. Apply plies G1, G2, and G3 per Table 8-5.

ce. Consolidate.

cf. Apply plies G4, G5, and G6 per Table 8-5.

cg. Consolidate.

ch. Measure and record Min. and Max. diameter at taper end of tube.

ci. Apply two 0° plies 17.4" long from tapered end of tube.

cj. Consolidate.

ck. Apply two 0° plies 17.4 inches long from tapered end of tube.

cl. Consolidate.

cm. Measure and record Min. and Max. diameter at three locations.

cn. Apply 90° ply over 0° plies - blend into last 90° ply.

co. Apply plies H1, H2, and H3 per Table 8-5.

cp. Consolidate.

cq. Apply plies H4, H5, and H6 per Table 8-5.

cr. Consolidate.

cs. Measure and record Min. and Max. diameter at taper end of tube.

ct. Apply two 0° plies 16.9° long from tapered end of tube.

cu. Consolidate.

cv. Apply two 0° plies 16.9 long from tapered end of tube.

cw. Consolidate.

cx. Measure and record Min. and Max. diameter at three locations.

cy. Apply 90° ply over 0° plies - blend into last 90° ply.

cz. Apply plies I1, L2, and I3 per Table 8-5.

da. Consolidate.

db. Apply plies I4, I5, and It per Table 8-5.

dc. Consolidate.

dd. Measure and record Min. and Max. diameter at taper end of tube.

de. Apply two 0° plies 16.5" long from tapered end of tube.

df. Consolidate.

dg. Apply two 0° plies 16.5" long from tapered end of tube.

dh. Consolidate.

di. Measure and record Min. and Max. diameter at three locations.

dj. Apply 90° ply over 0° plies - blend into last 90° ply.

dk. Apply plies J1, J2, and J3 per Table 8-5.

dl. Consolidate.

dm. Apply plies J4, J5, and J6 per Table 8-5.

dn. Consolidate.

do. Measure and record Min. and Max. diameter at tapered end of tube.

dp. Apply two 0° plies 16.0" long from tapered end of tube.

dq. Consolidate.

dr. Apply two 0° plies 16.0" long from tapered end of tube.

ds. Consolidate.

dt. Measure and record Min. and Max. diameter at three locations.

du. Apply 90° ply over 0° ply - blend into last 90° ply.

dv. Apply two 0° plies 15.6" long from tapered end.

dw. Consolidate.

dx. Apply two 0° plies 15.6" long from tapered end.

dy. Consolidate.

dz. Measure and record Min. and Max. diameter at three locations.

ea. Apply 90° ply over 0° ply - blend into last 90° ply.

eb. Insure that the size of the tube meets the minimum dimensions of the drawing VXD 31098, Rev. B.

ec. Apply one layer sheet resin over outer surface of tube.

ed. Consolidate.

10. Cure Preparation.

a. Apply 3" diameter shrink tubing to outer surface of tube using manufacturer's recommendations.

b. Apply two plies TX-1040 Teflon coated glass scrim.

c. Apply one ply Armalon Teflon coated glass cloth.

d. Apply thermocouple.

e. Apply vacuum bag.

f. Install in autoclave pressure.

11. Cure

a. Apply vacuum.

b. Apply 100 psi autoclave pressure.

c. Apply heat in the following sequence:

(1) 180°F for ½ hour
(2) 280°F for ½ hour
(3) 350°F for 1 hour.

d. Cool down to room temperature maintaining pressure and vacuum during cooldown.

12. Remove from autoclave.

13. Remove vacuum bag, thermocouple, glass cloth, and teflon shrink tubing.

14. Place assembly in dry ice.

15. Disassemble and remove aluminum mandrels.

16. Allow unit to come up to room temperature

17. Remove salt mandrel by using water to wash.

18. Machine off ends.

19. Ship to Automation Industries for C-scan.

20. Ship to Bendix.

General

(a) The 0° and 45° lamina were applied by hand layup of uni-directional broad goods. The 90° lamina were applied by the circumferential winding of two filaments at 108 turns per inch. The tensile load applied to the filaments during winding was approximately 85% of the breaking strength of the filaments under winding conditions.

(b) Vacuum used during the consolidation and curing operations was between 28 and 29 inches Hg. (Cumberland, Maryland)

(c) The dimensional results after each consolidation step are given in Table 8-6.

After fabrication, the composite tube was shipped to Automation Industries, Danbury, Connecticut, for C-scan inspection. The results are shown in Figure 8-84.

TABLE 8-4. LAMINA INSIDE TAPER

Sequence	Number	Angle	Dimension	Length	Distance from Tapered End of Mandrel
A	1	+45	.033	5.517	5.557
	2	-45	.200	5.350	5.390
	3	+45	.367	5.183	5.223
	4	-45	.533	5.017	5.057
	5	+45	.700	4.850	4.890
	6	-45	.867	4.683	4.723
B	1	+45	.067	5.483	5.523
	2	-45	.233	5.317	5.357
	3	+45	.400	5.150	5.190
	4	-45	.567	4.983	5.023
	5	+45	.733	4.817	4.857
	6	-45	.900	4.650	4.690
C	1	+45	.100	5.450	5.490
	2	-45	.267	5.283	5.323
	3	+45	.433	5.117	5.157
	4	-45	.600	4.950	4.990
	5	+45	.767	4.783	4.823
	6	-45	.933	4.617	4.657
D	1	+45	.133	5.417	5.457
	2	-45	.300	5.250	5.290
	3	+45	.467	5.083	5.123
	4	-45	.633	4.917	4.957
	5	+45	.800	4.750	4.790
	6	-45	.967	4.583	4.623
E	1	+45	.167	5.383	5.423
	2	-45	.333	5.217	5.257
	3	+45	.500	5.050	5.090
	4	-45	.667	4.883	4.923
	5	+45	.833	4.717	4.757
	6	-45	1.000	4.550	4.590

TABLE 8-5. LAMINA OUTSIDE TAPER

Sequence	Number	Angle	Reference Dimension	Length	Distance from Tapered End of Mandrel
F	1	+45	.083	3.847	3.887
	2	-45	.500	3.430	3.470
	3	+45	.917	3.013	3.053
	4	-45	1.333	2.597	2.637
	5	+45	1.750	2.180	2.220
	6	-45	2.167	1.763	1.803
G	1	+45	.167	3.763	3.802
	2	-45	.583	3.347	3.387
	3	+45	1.000	2.930	2.970
	4	-45	1.417	2.513	2.553
	5	+45	1.833	2.097	2.137
	6	-45	2.250	1.680	1.720
H	1	+45	.250	3.680	3.720
	2	-45	.667	3.263	3.303
	3	+45	1.083	2.847	2.887
	4	-45	1.500	2.430	2.470
	5	+45	1.917	2.013	2.053
	6	-45	2.333	1.597	1.637
I	1	+45	.333	3.597	3.637
	2	-45	.750	3.180	3.220
	3	+45	1.167	2.763	2.803
	4	-45	1.583	2.347	2.387
	5	+45	2.000	1.930	1.970
	6	-45	2.417	1.513	1.553
J	1	+45	.417	3.513	3.553
	2	-45	.833	3.097	3.147
	3	+45	1.250	2.680	2.720
	4	-45	1.667	2.263	2.303
	5	+45	2.083	1.847	1.887
	6	-45	2.500	1.430	1.470

TABLE 8-6. DIMENSIONAL RESULTS

Nickel Plated Mandrel	Ply Number	LOCATION 1 1" From 2.670 End 0° Dia.	LOCATION 1 90° Dia	LOCATION 1 Diff.	LOCATION 2 12" From 2.670 End 0° Dia.	LOCATION 2 90° Dia.	LOCATION 2 Diff.	LOCATION 3 1" From Tailstock	LOCATION 3 0° Dia.	LOCATION 3 90° Dia.	LOCATION 3 Diff.
1st Consol., Step d	1 & 2	2.197	2.197	.000	2.194	2.201	.007		1.904	1.905	.001
2nd Consol., Step h	3 & 4	2.216	2.215	.001	2.214	2.212	.002		1.925	1.925	.000
3rd Consol., Step n	5 after 90° Wind	2.222	2.223	.001	2.220	2.220	.000		1.931	1.931	.000
4th Consol., Step q	6 & 7	2.248	2.246	.002	2.243	2.244	.001	After 6 Plies ± 45°	2.020	2.017	.003
5th Consol., Step u	8 & 9	2.264	2.265	.001	2.264	2.265	.001		2.042	2.039	.003
6th Consol., Step aa	10 After 90° Wind	2.268	2.270	.002	2.268	2.270	.001	After 6 Plies ± 45°	2.110	2.106	.004
7th Consol., Step ad	11 & 12	2.291	2.293	.002	2.290	2.292	.002		2.130	2.126	.004
8th Consol., Step ah	13 & 14	2.312	2.315	.003	2.311	2.313	.002		2.146	2.144	.002
9th Consol., Step an	15 After 90° Wind	2.316	2.318	.002	2.315	2.317	.002	After 6 Plies ± 45°	2.222	2.220	.002
10th Consol., Step aq	16 & 17	2.340	2.343	.003	2.340	2.340	.000		2.237	2.232	.000
11th Consol., Step au	18 & 19	2.360	2.362	.002	2.358	2.358	.000		2.255	2.253	.002
12th Consol., Step ba	20 After 90° Wind	2.365	2.367	.002	2.364	2.365	.001	After 6 Plies ± 45°	2.320	2.323	.003
13th Consol., Step bf	21 & 22	2.392	2.394	.002	2.389	2.391	.002		2.344	2.345	.001
14th Consol., Step bl	23 & 24	2.413	2.413	.000	2.406	2.408	.002		2.362	2.360	.002
15th Consol., Step bq	25 After 90° Wind	2.415	2.416	.001	2.413	2.417	.004	After 6 Plies ± 45°	2.429	2.427	.002
16th Consol., Step bw	26, 27, 28, 29 4" From Liner End	2.467	2.466	.001	2.462	2.461	.001		2.466	2.470	.004
17th Consol., Step cb	30							After 6 Plies ± 45°	2.527	2.527	.000
18th Consol., Step ch	31, 32, 33, 34 4½" From Liner End	2.505	2.505	.000	2.501	2.503	.002		2.567	2.566	.001
19th Consol., Step cm	35 90° 4 3/4" From Liner End	2.509	2.509	.000	2.504	2.507	.003	After 6 Plies ± 45°	2.637	2.634	.003
20th Consol., Step cs	36, 37, 38, 39 5½" From Liner End	2.565	2.560	.005	2.555	2.560	.005		2.676	2.676	.000
21st Consol., Step cx	40 After 90° Wind	2.571	2.568	.003	2.563	2.567	.004	After 6 Plies ± 45°	2.746	2.749	.003
22nd Consol., Step da	41, 42, 43 & 44	2.608	2.607	.001	2.604	2.606	.002		2.780	2.784	.004
23rd Consol., Step di	45 After 90° Wind	2.613	2.612	.001	2.610	2.611	.001	After 6 Plies ± 45°	2.847	2.851	.004
24th Consol., Step do	46, 47, 48 & 49	2.650	2.648	.002	2.649	2.649	.000		2.887	2.888	.001
25th Consol., Step dt	50 After 90° Wind	2.660	2.659	.001	2.654	2.655	.001	After 6 Plies ± 45°	2.949	2.959	.010
26th Consol., Step dz	51, 52, 53 & 54	2.706	2.704	.002	2.697	2.697	.000		2.994	2.997	.003
Final Consol., Step eb	55, 56, & 57 After 90°	2.730	2.731	.001	2.730	2.732	.002		3.016	3.021	.005
		2.734	2.735	.001	2.731	2.731	.000		3.024	3.029	.005

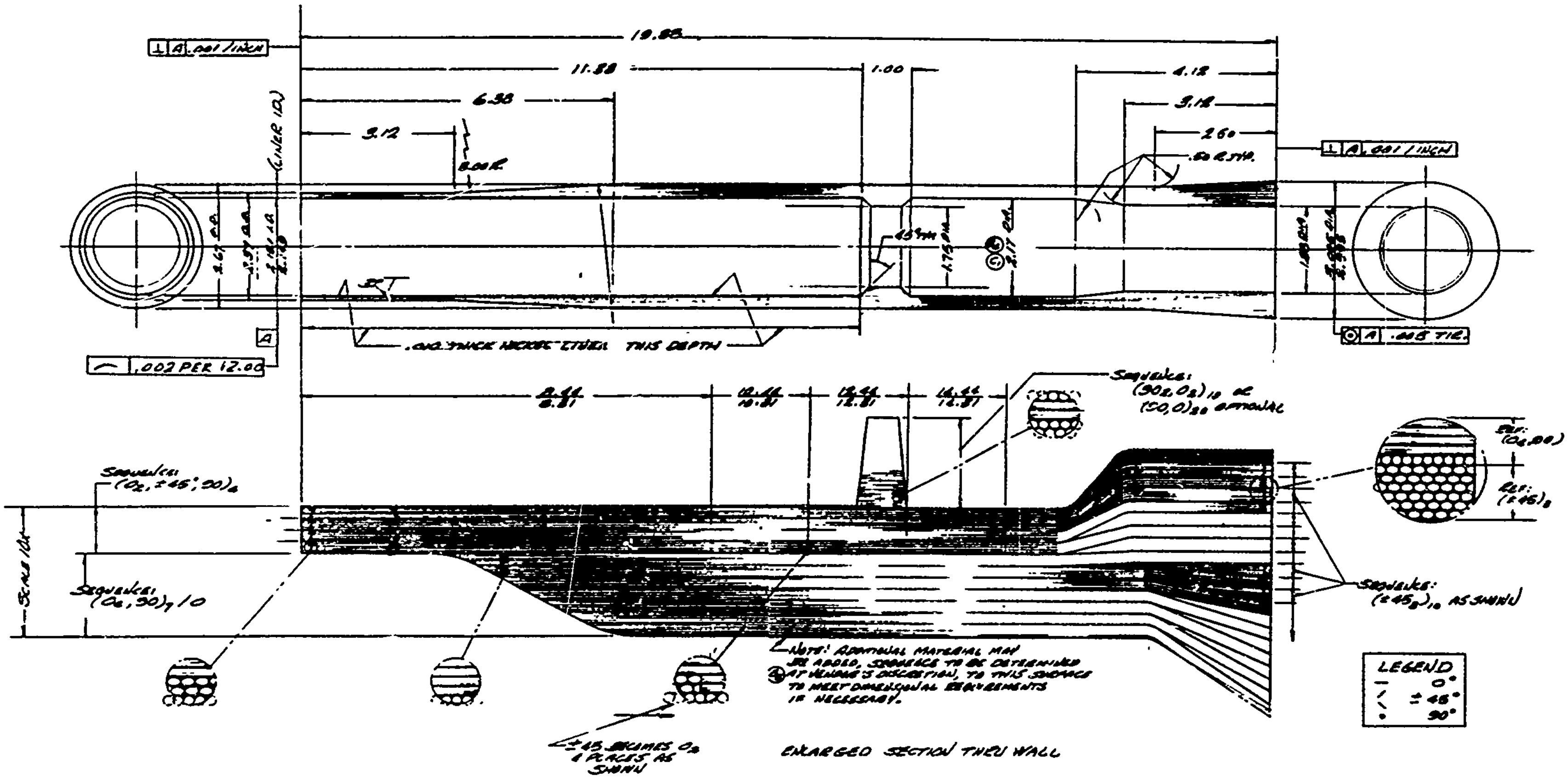


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Figure 8-83. Boron-Epoxy Piston Cylinder

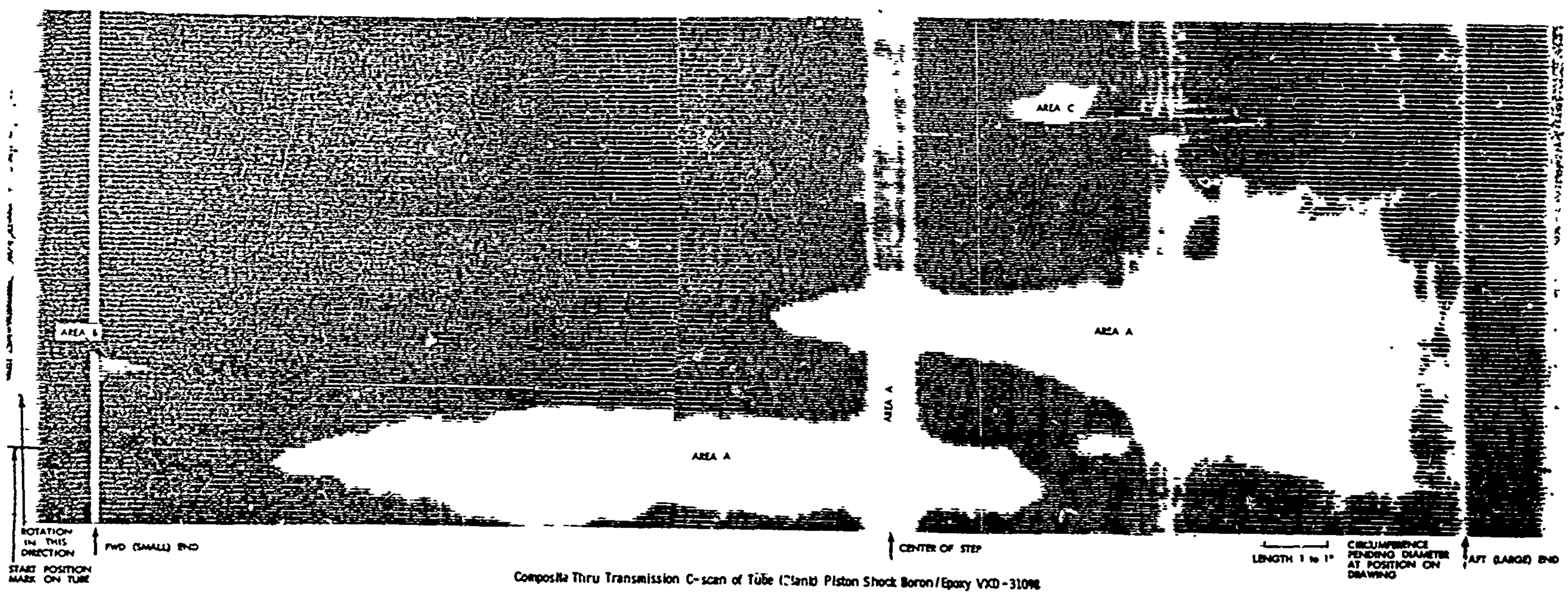


Figure 8-84. Piston Cylinder C-Scan

2. Bendix Activities (Prototype Piston-Axle)

The fabrication effort applied by Bendix was performed in the following steps.

1. Inspection - The cylinder as delivered to Bendix is illustrated in Figures 8-85 and 8-86. Two defects were evident in this cylinder: Failure of the inner nickel liner to adhere to the boron composite tube and severe delamination of the plies. The separated liner is shown in the photographs and the wall delamination is apparent from the C-scan transmission supplied with the tube, Figure 8-84. Repairs applied to compensate for these discrepancies are described below.

Hercules investigation of the liner did not reveal an exact cause for the low quality bond. The most significant factor appeared to be the time involved between cleaning the OD of the nickel liner and the start of the actual lay up of the boron-epoxy broad goods on this surface. After the nickel liner was cleaned, a protective cover was placed over the surface while the metering pin support ledge was fabricated. Approximately three weeks were spent working on the support ledge. When construction of the tube was started, the cover over the nickel was removed and the lay up was started without any further cleaning operations. It is believed that the three week period between cleaning and bonding could be part of the problem.

2. Machining - The basic cylinder was machined to its final configuration in the Bendix shop. The overall result is shown in Figure 8-87. Cropping of the ends Figure 8-88, uncovered the ply delamination indicated by the C-scan. Machining of the outside contour produced a blister, apparently the result of breaking through one of the loose delaminated plies, Figure 8-89. (Repair of this flaw is described below.) Machining of the lower end conical taper produced contour lines of what appear to be ply ends, Figure 8-90. These contour lines were unexpected since the intention was to produce a ply layup and machining contour which are parallel at this surface. The reason for this result became apparent when performance tests were completed after which the cylinder was sectioned lengthwise, paragraph 7.

3. Repair Procedure for Cylinder

1. Liner Separation -

It did not appear that there was a feasible procedure for bonding an ID liner to a preformed cylinder. It was therefore decided to attempt to use the piston without an ID liner.

The intended purpose of the inner liner was various: To provide a barrier to penetration of the tube wall by hydraulic fluid, to provide a smooth surface for metering pin diaphragm seal, and to provide a mooth stroking surface for the orifice support tube seal (Figure 6-6). A check of the interior surface of the unlined cylinder indicated a surface finish which appeared suitable for the loose seal to run on, particularly since no significant radial bearing load is involved. In addition a proof pressure test (described below indicated that no gross problems in fluid permeation of the wall or leakage around the O-ring seal would be encountered by using the piston without an inner liner. Therefore

the linerless piston cylinder was adapted to use by installing oversize parts for the metering pin support diaphragm and orifice diaphragm seals.

Proof Pressure Test

A pressure mandrel was inserted in the cylinder as illustrated in Figures 8-91, 8-92, and 8-93. Water was used as the charging medium. Regular hydraulic fluid was not used in order not to contaminate the cylinder surface in case it was later necessary to apply bonding agents to stop any resulting leakage through the wall. The cylinder was loaded as follows:

Pressure, Psi	
Position 1	Position 2
200	500
300	1000
400	1500

Each pressure was held for 15 minutes. No leakage was detected either visually or by monitoring pressure drop. From this test it was concluded that no gross leakage defects exist with this piston.

2. Delamination -

The tube was returned to Hercules where repair of two areas of the tube was undertaken. One area was at the smaller end of the tube where loose fibers broke through the outside surface, Figure 8-89. The second case for concern was the gaps in the thick end of the tube, Figure 8-88.

Repair Procedure

In each case the repair media was a room temperature curing epoxy having as a base ingredient Epon 826 resin. Although the actual formulation of BP 907 is proprietary, it has been deducted that the main ingredient is Epon 826 or 828. Therefore, it appears that the repair resin would be compatible with the cured BP 907.

Repair Ingredients

The following ingredients were mixed.

	P.B.W.
Epon 826	200
RTA (Room Temperature Activator)	8
RTH (Room Temperature Hardener)	115
TPP (Tri-Phenol Phosphide)	40
SR 82 Silicone	12
	375

After mixing they were placed in a vacuum desiccator to remove air bubbles.

Tube Preparation, Thick End

Masking tape was placed both on the ID and OD of the tube, extending 1/2 inch beyond the end of the tube. The tube was placed in the vacuum desiccator with the thick end up, Figure 8-94. Resin was placed on the end of the tube to a depth of approximately 1/8 inch. A transparent cover was placed on the desiccator and vacuum pulled. Air bubbles rose out of the gaps in the tube and resin filled the voids. Vacuum was left on for approximately four hours. The tube was removed from the desiccator and the resin allowed to cure. After cure the excess resin was filled and sanded to a smooth surface, Figure 8-95.

Smaller End

Resin was placed on the surface of the tube in the repair area and the tube placed in the desiccator in a horizontal position so more resin could be added to the area as needed. The resin was allowed to cure and sanded to conform to the contour of the tube in that area, Figure 8-96.

Repair work appears to be successful; however, no attempt was made to determine the resin penetration. This will be determined by sectioning the tube lengthwise after performance tests have been completed. If penetration was significantly deep, future repairs may be accomplished in a similar manner.

The repaired tube was crated and shipped to Electroforms Incorporated in Gardena, California for nickel plating of the OD of the tube.

4. Deposition of OD Nickel Plate - The purchase order to Electroforms specified Grade V Nickel plating of the outer surface in accordance with Figure 8-97 and Paragraph 8.2.7 of this report. The plated tube delivered to Bendix had the general appearance shown in Figure 8-98. In detail, some surface blemishes are apparent. At the lower end of the piston various cracks were apparent around the periphery as shown in Figure 8-99. In the main body of the tube a number of cavities were evident, Figures 8-100 and 8-101. There was concern that these cavities were too deep to clean up during subsequent machining.

5. Machining of OD Nickel Plate - The outer liner was machined by Bendix to the final dimensions indicated in Figure 8-97. After machining, the piston had the general appearance shown in Figure 8-102. In the main body of the piston the machining process uncovered the subsurface flaw shown in Figure 8-103.

6. Fittings - The required conventional metallic fittings and axle were procured or fabricated by Bendix.

7. Final Assembly - Final assembly of metal hardware to the composite cylinder was performed in the following steps.

(a) Valve guide and glass wound bearing adapter were applied to the cylinder, Figure 8-97.

(b) The axle and cylinder were assembled as shown in Figure 8-104.

(c) Rings, bearings, spacer tube, and rebound valve installed over cylinder as shown in Figure 8-105.

(d) Fiber glass retainer for upper bearing assembly wet-wound in place and cured, Figure 8-106.

(e) The completed piston-axle assembly is shown in Figure 8-107.

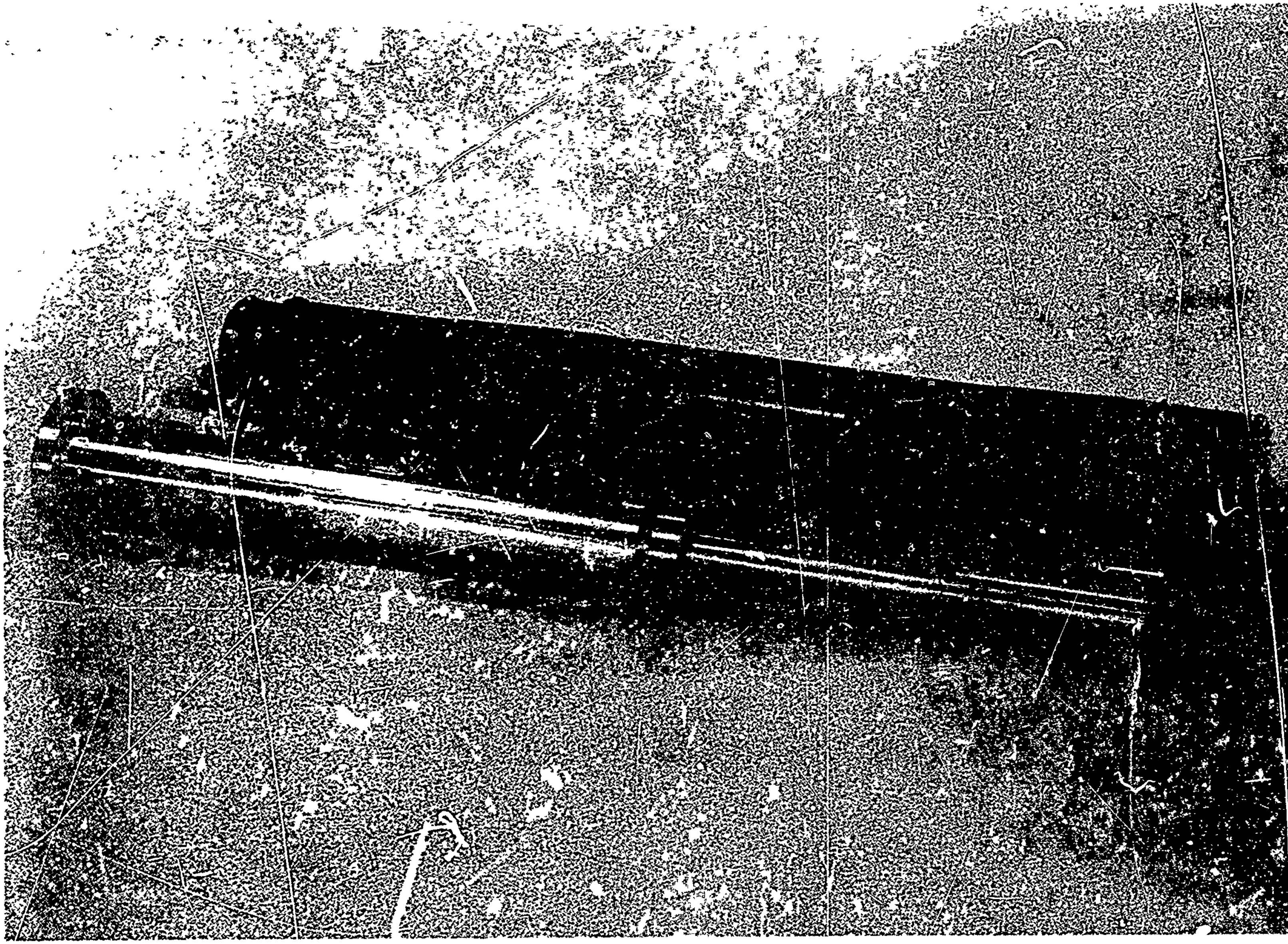


Figure 8-85. Piston as Wound, Loose Lines, Partial Mandrel

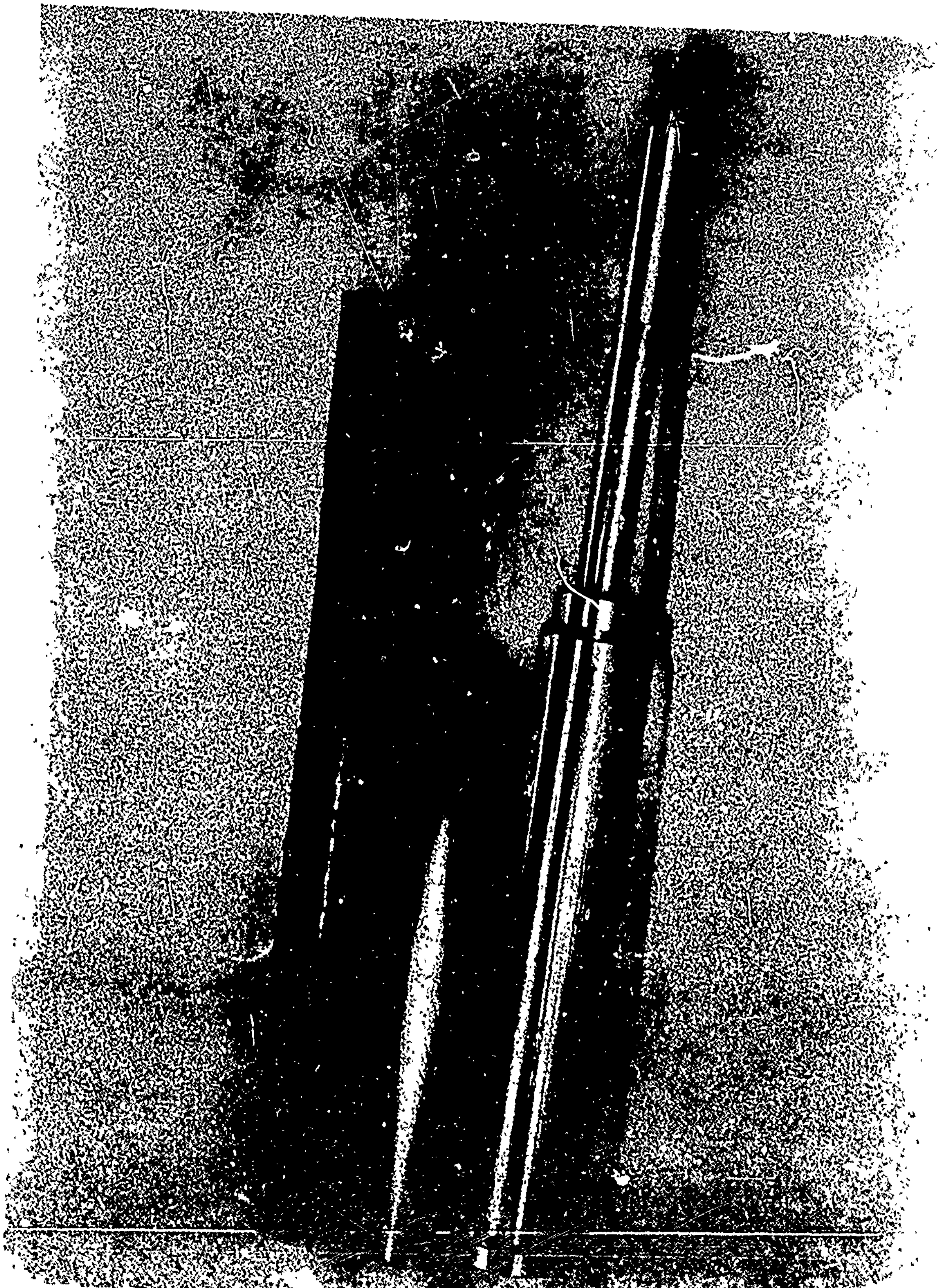


Figure 8-86. Piston with Loose Liner Removed

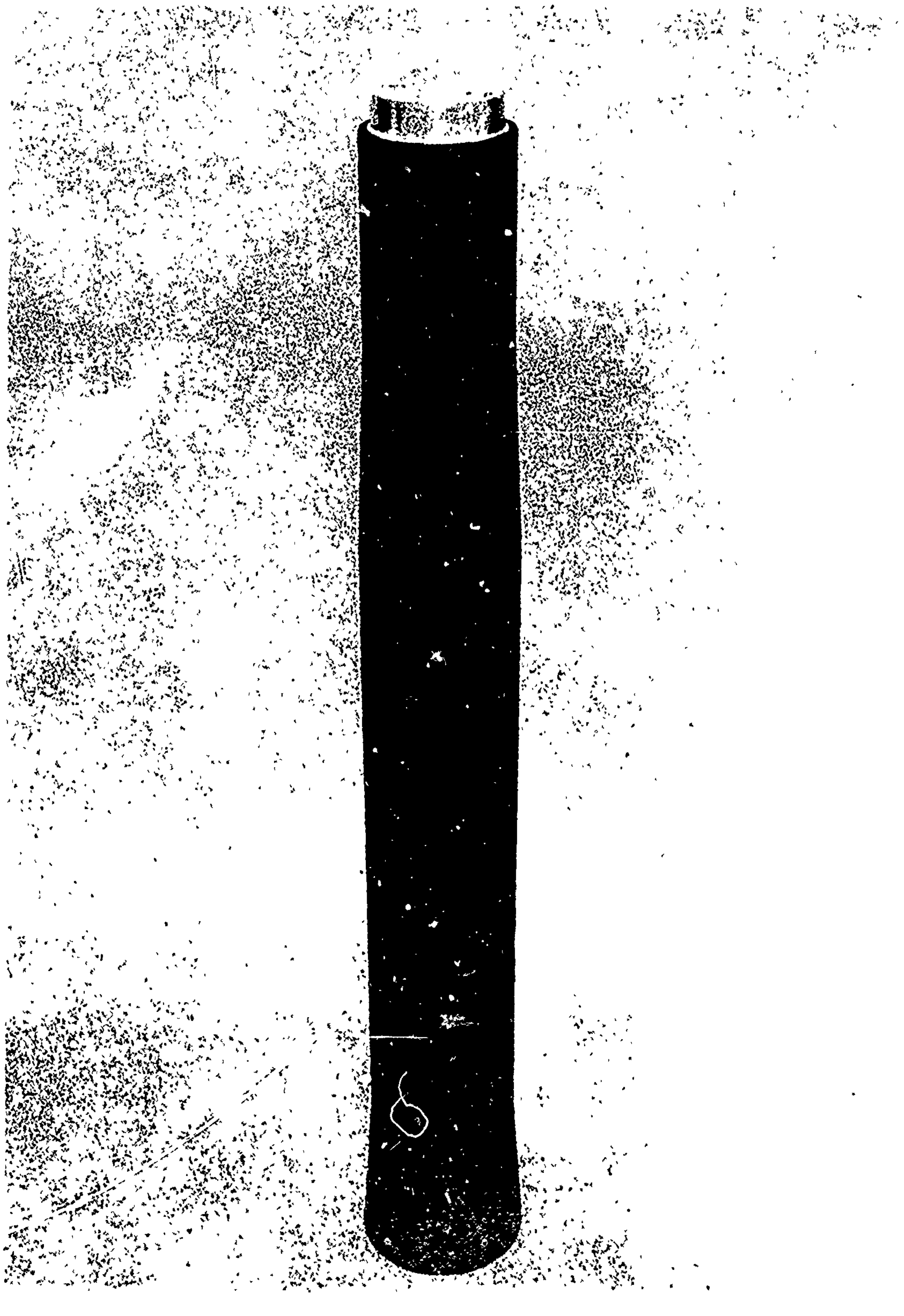


Figure 8-87. Piston OD As Machined

Figure 8-88. Thick End of Piston As Machined

Figure 8-89. Upper End of Piston As Machined

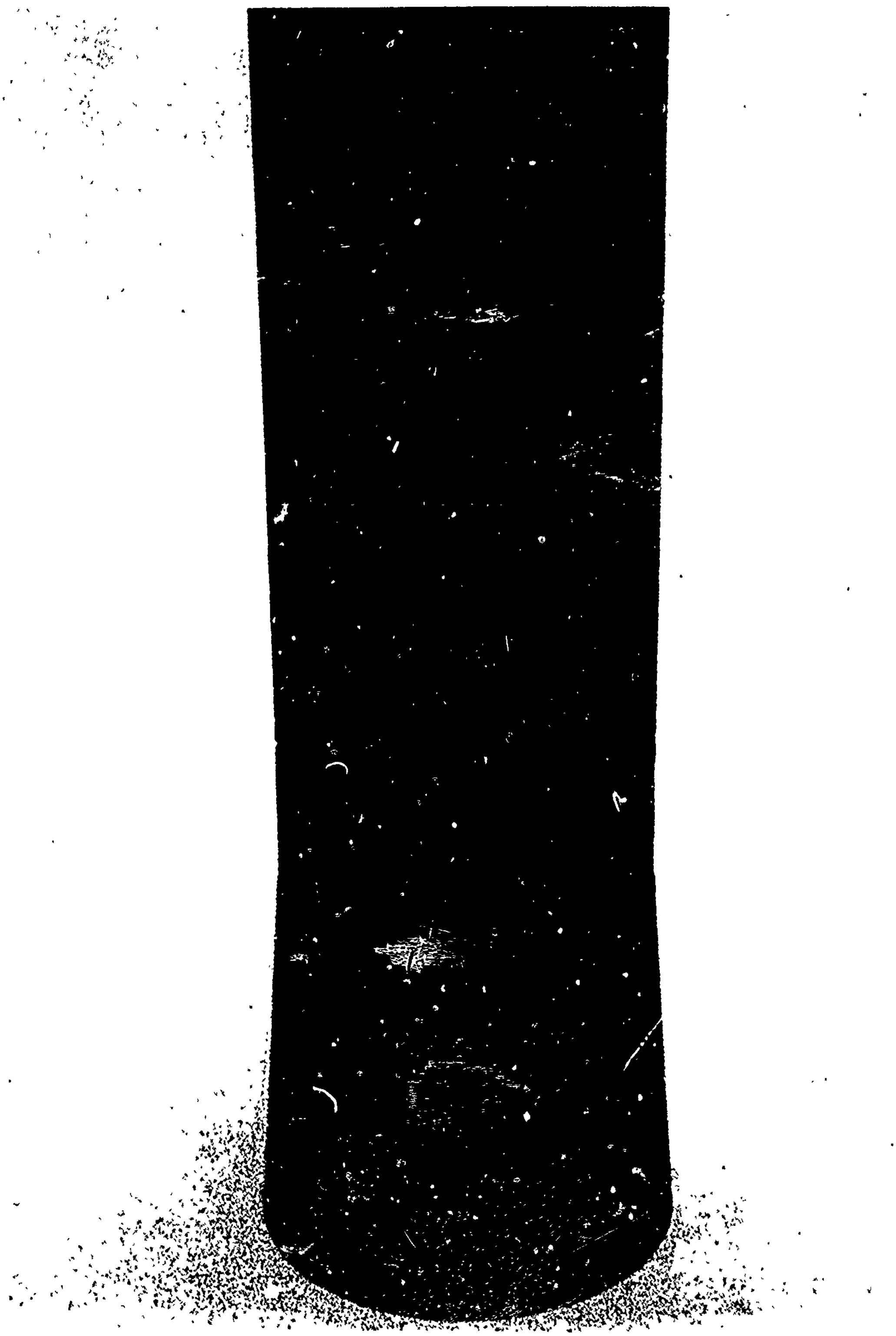
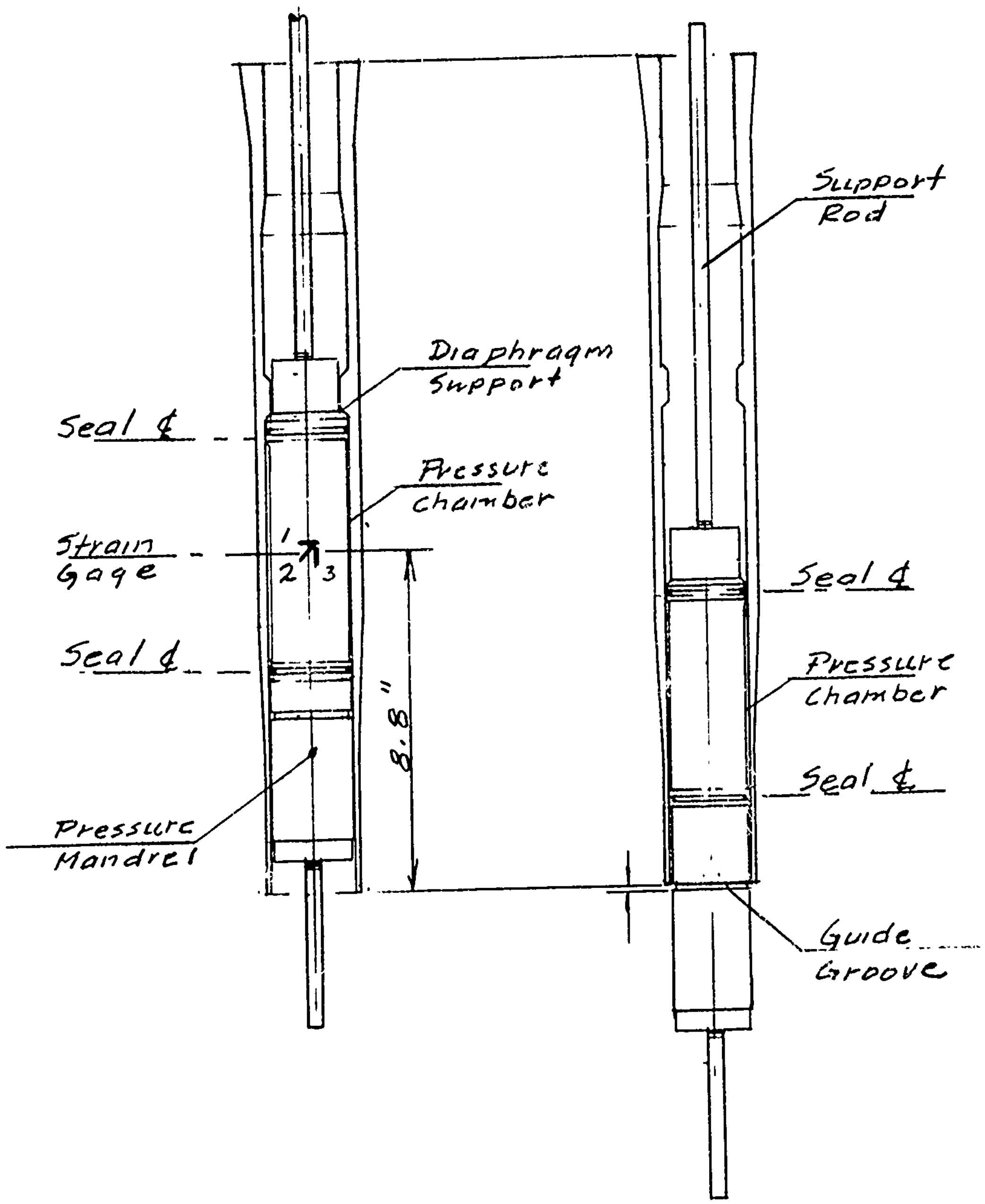


Figure 8-90. Lower End of Piston As Machined



Position 2

Position 1

Figure 8-91. Proof Pressure Test Schematic

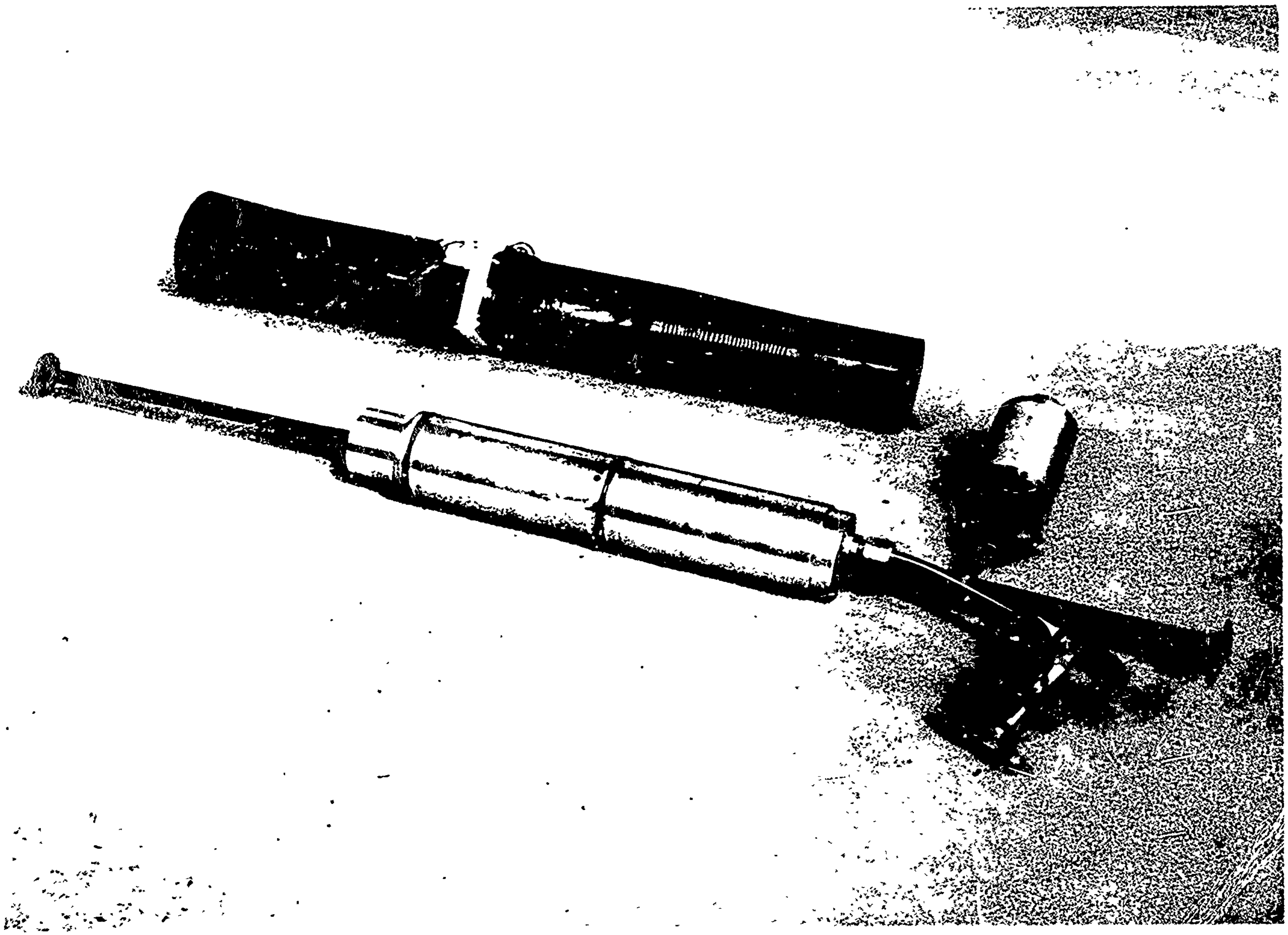


Figure 8-92. Piston and Pressure Test Mandrel

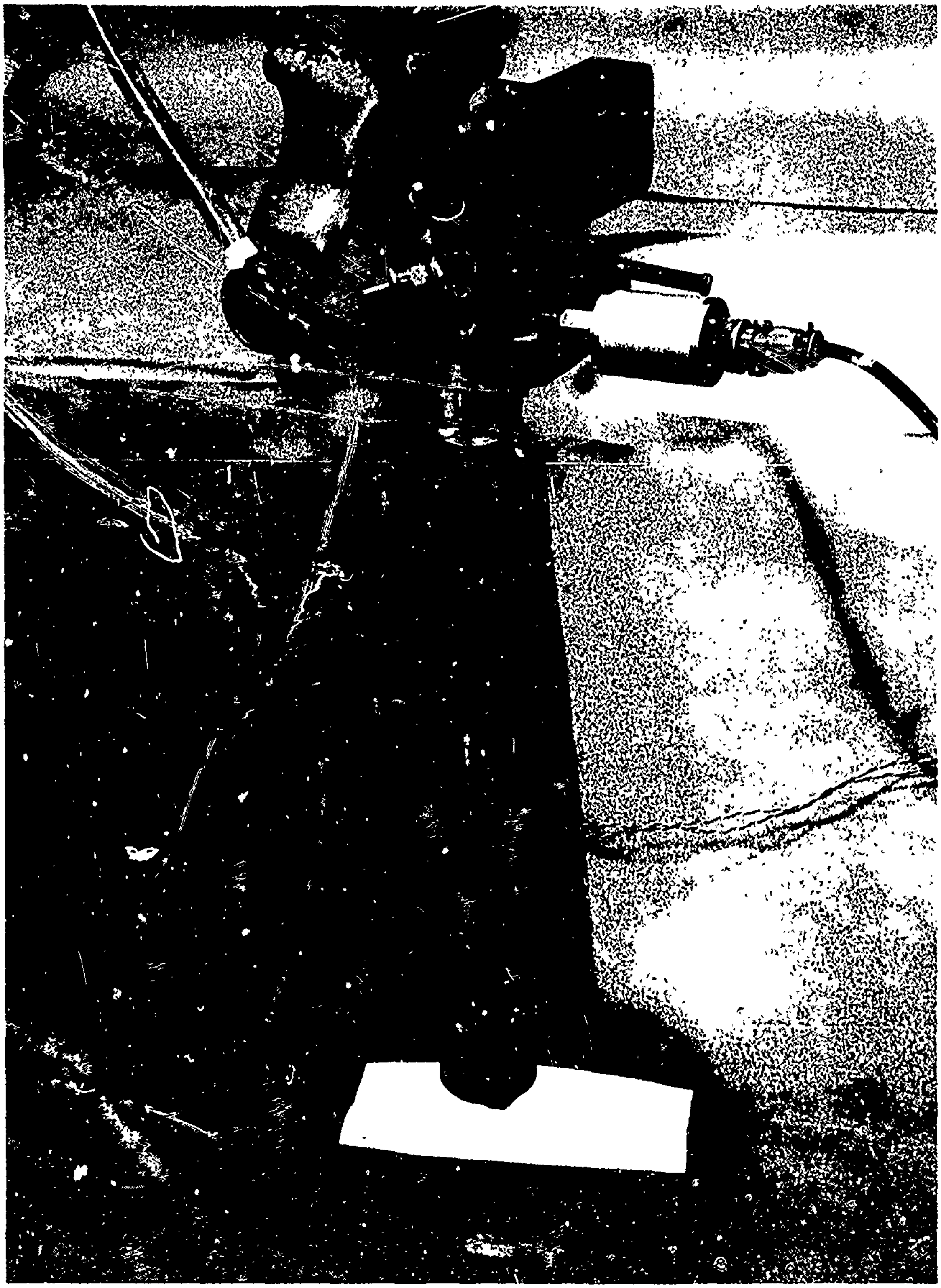


Figure 8-93. Setup for Proof Pressure Test

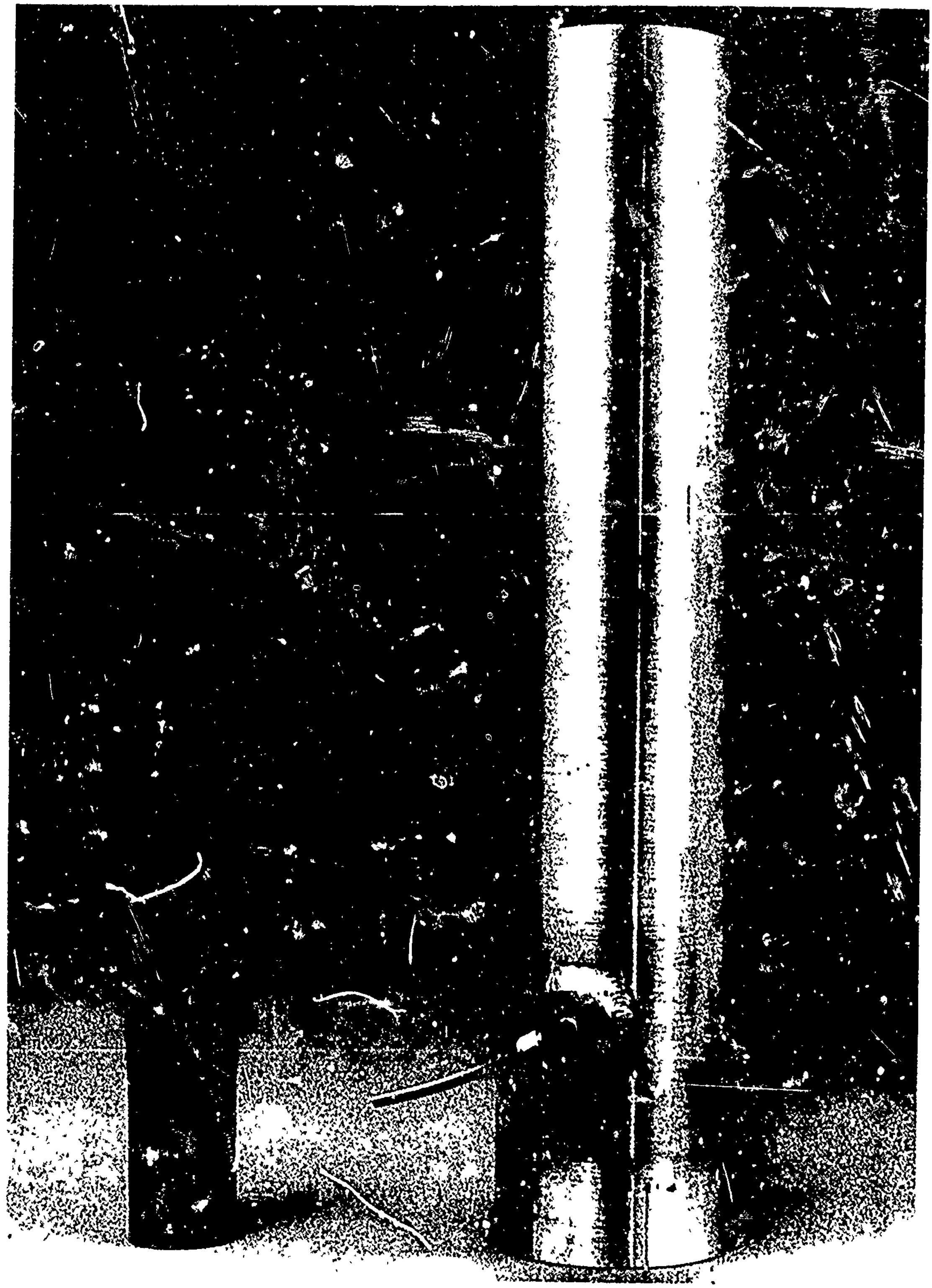


Figure 8-94. Vacuum Desiccator

Figure 8-95. Piston End After Repairs

Figure 8-96. Piston Upper End After Repairs

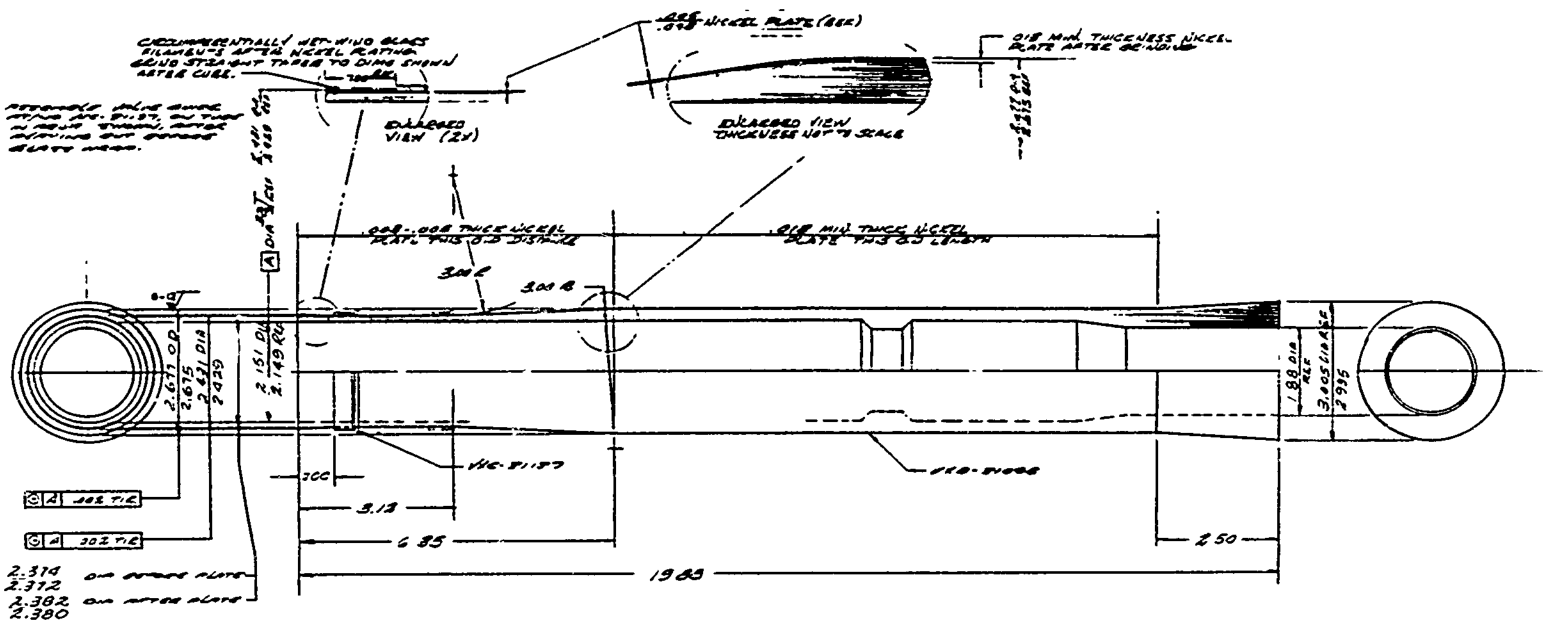


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Figure 8-97. Piston Cylinder Machining

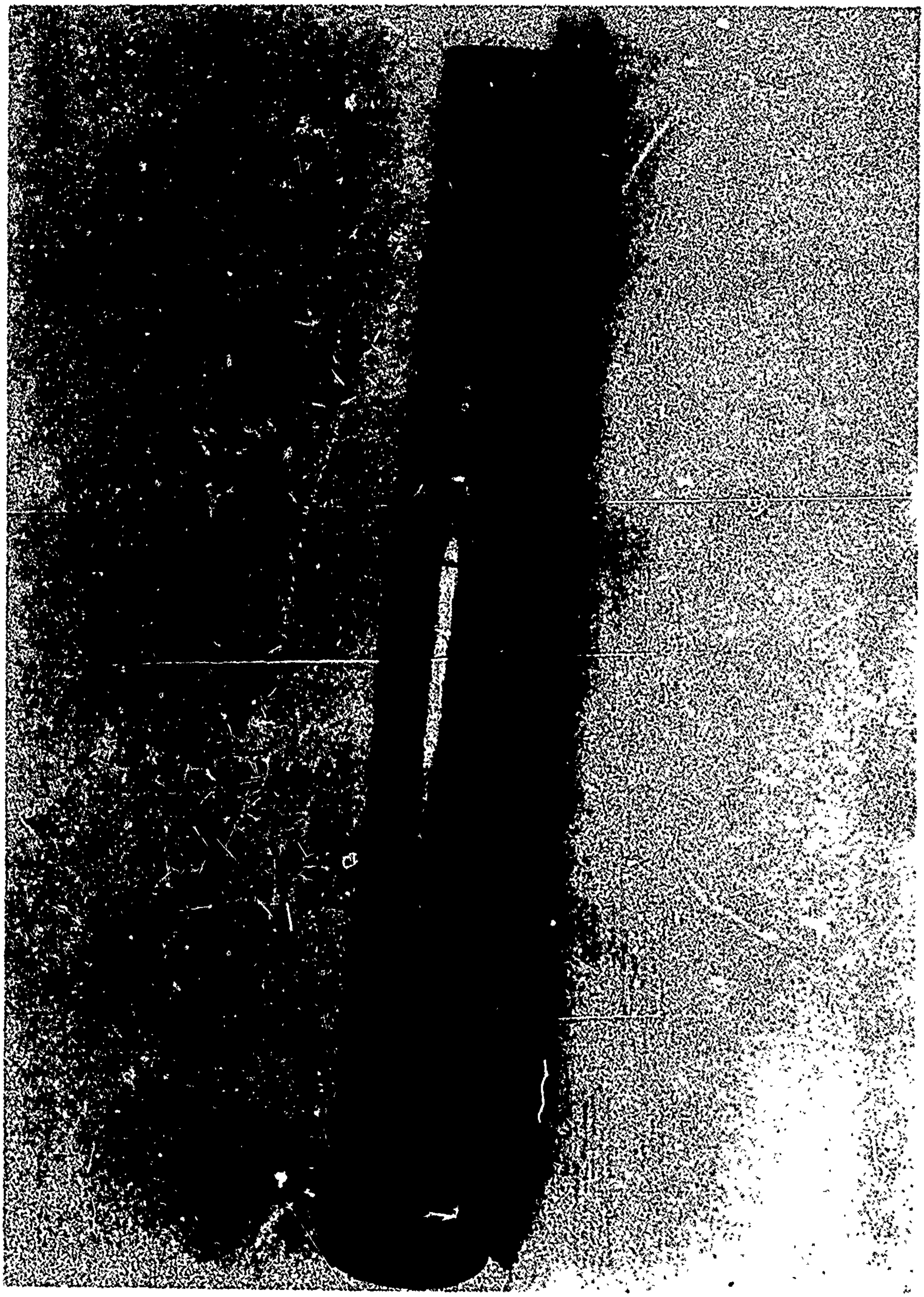

Figure 8-98. Piston OD As Nickel Plated

Figure 8-99. Crack in Nickel, Lower End Piston

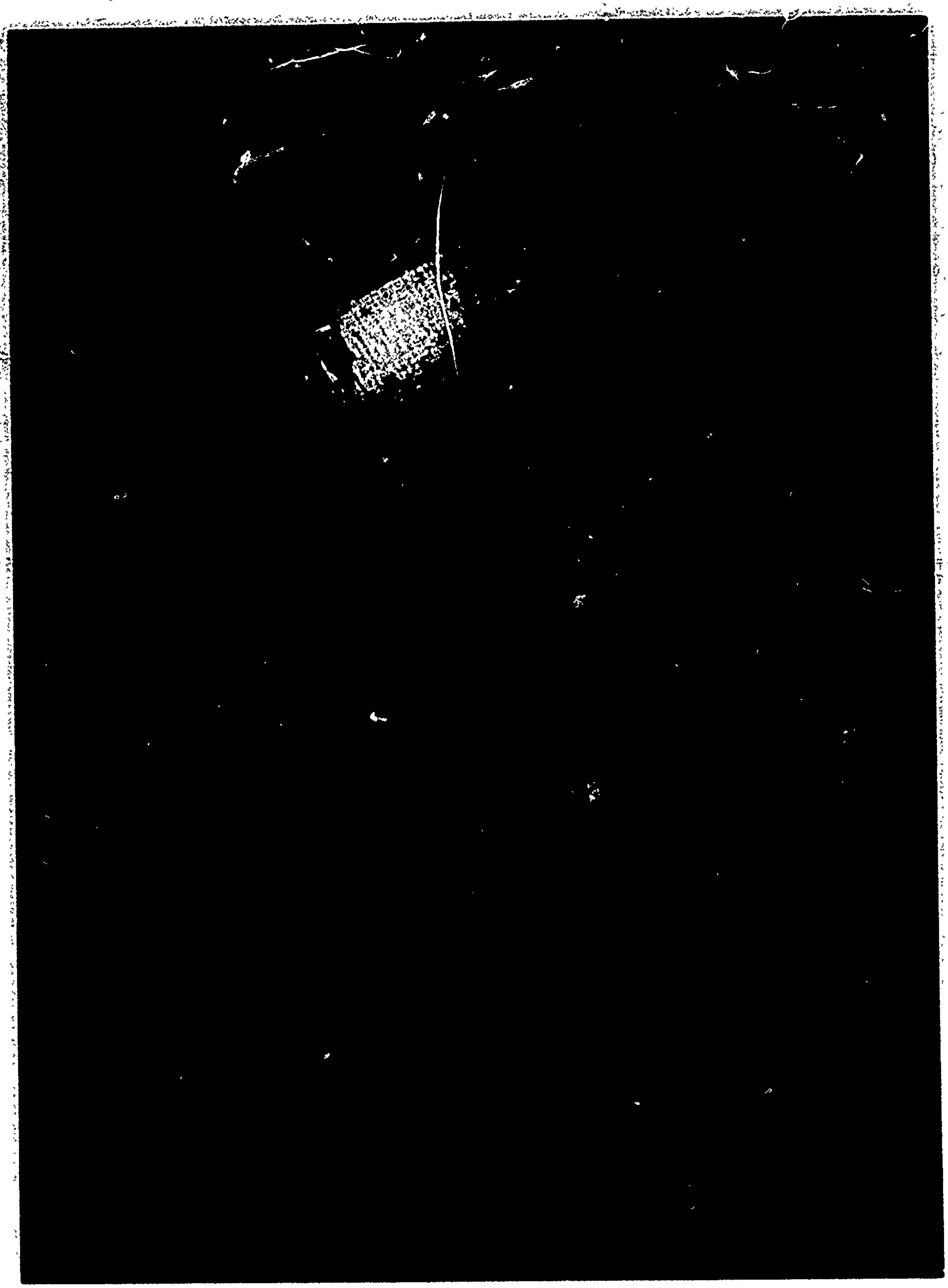

Figure 8-100. Cavity in As-Plated Surface

Figure 8-101. Cavity in As-Plated Surface

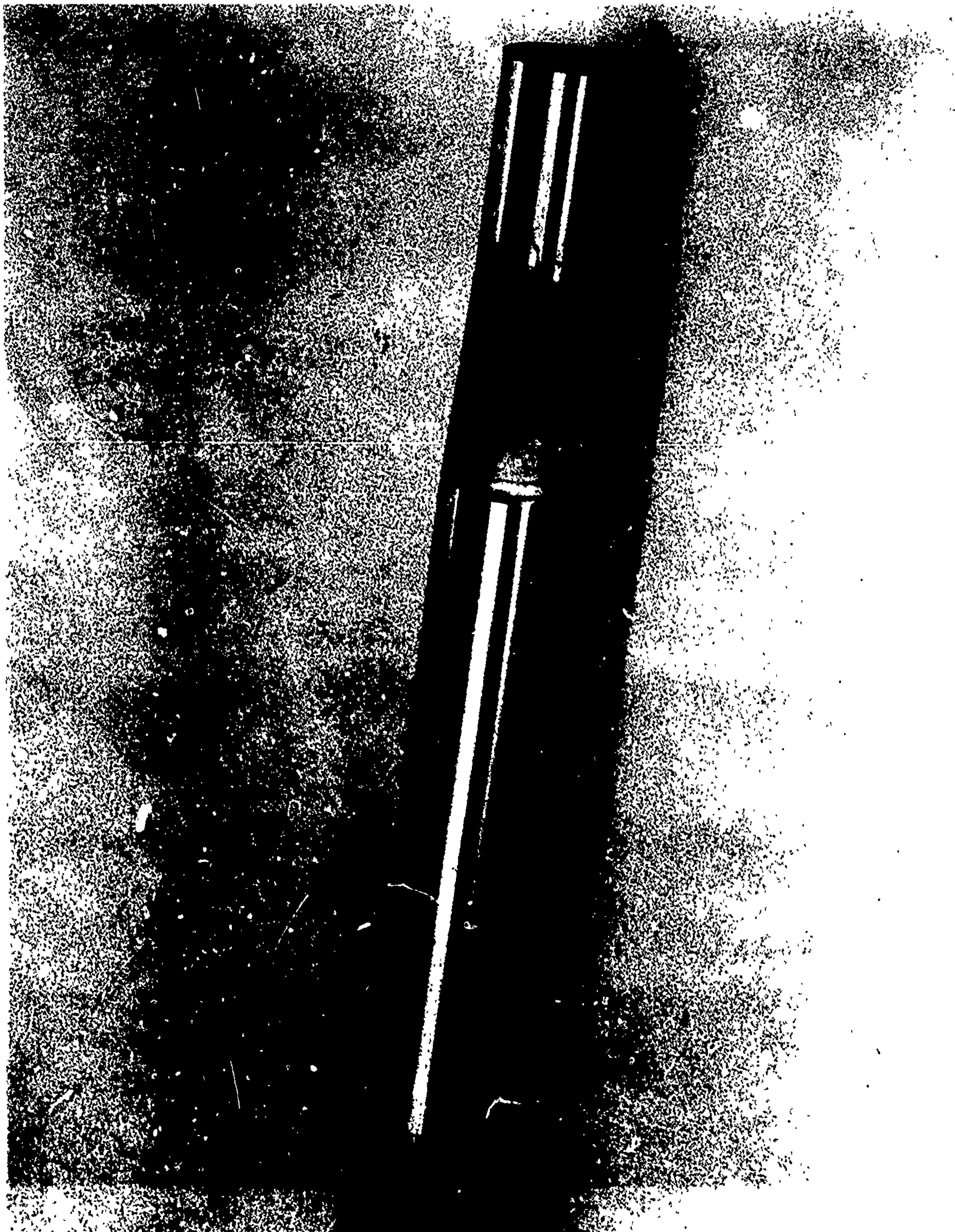

Figure 8-102. Outer Nickel Liner As Machined

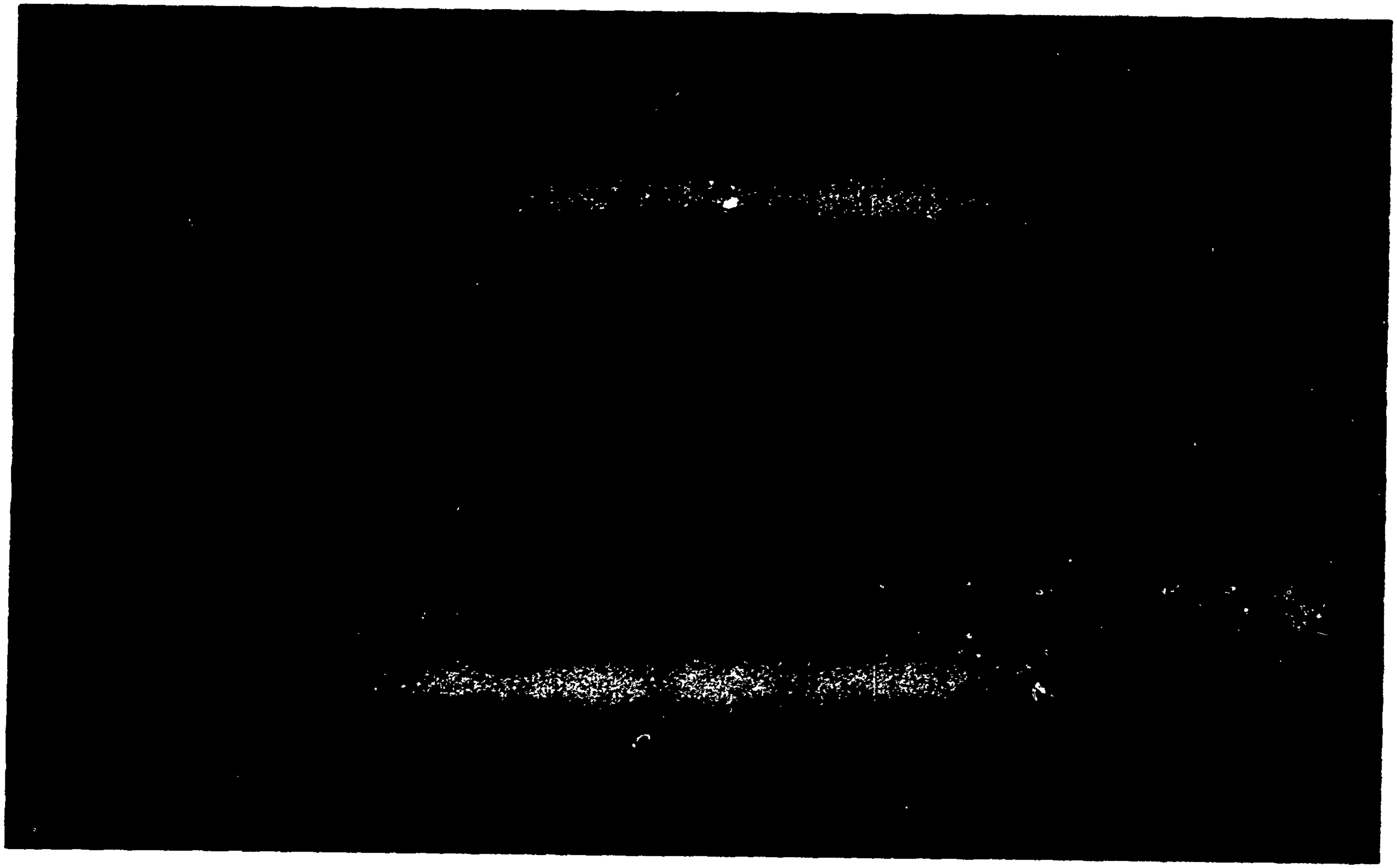

Figure 8-103. As Machined Nickel Surface, Subsurface Flaw

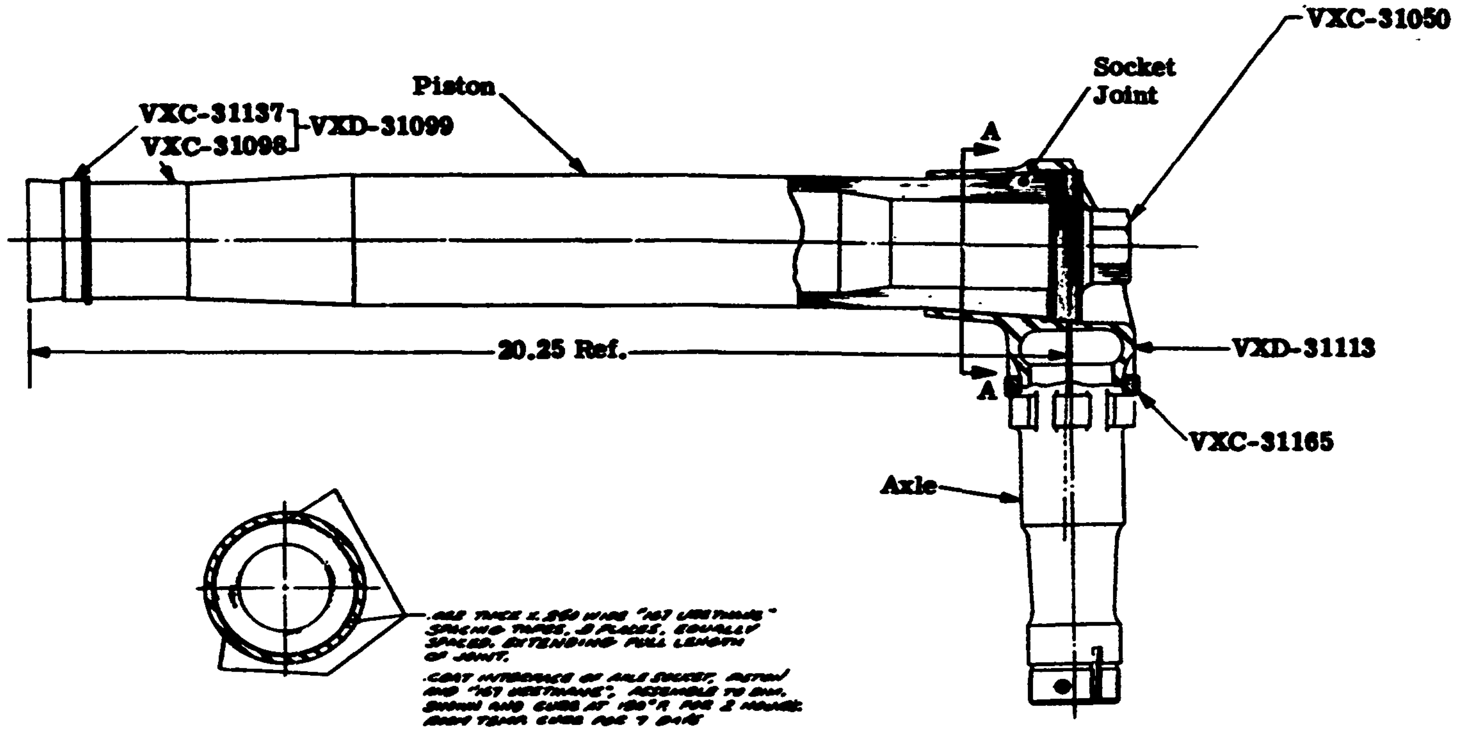

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Figure 8-104. Piston and Axle Assembly (Test Version)

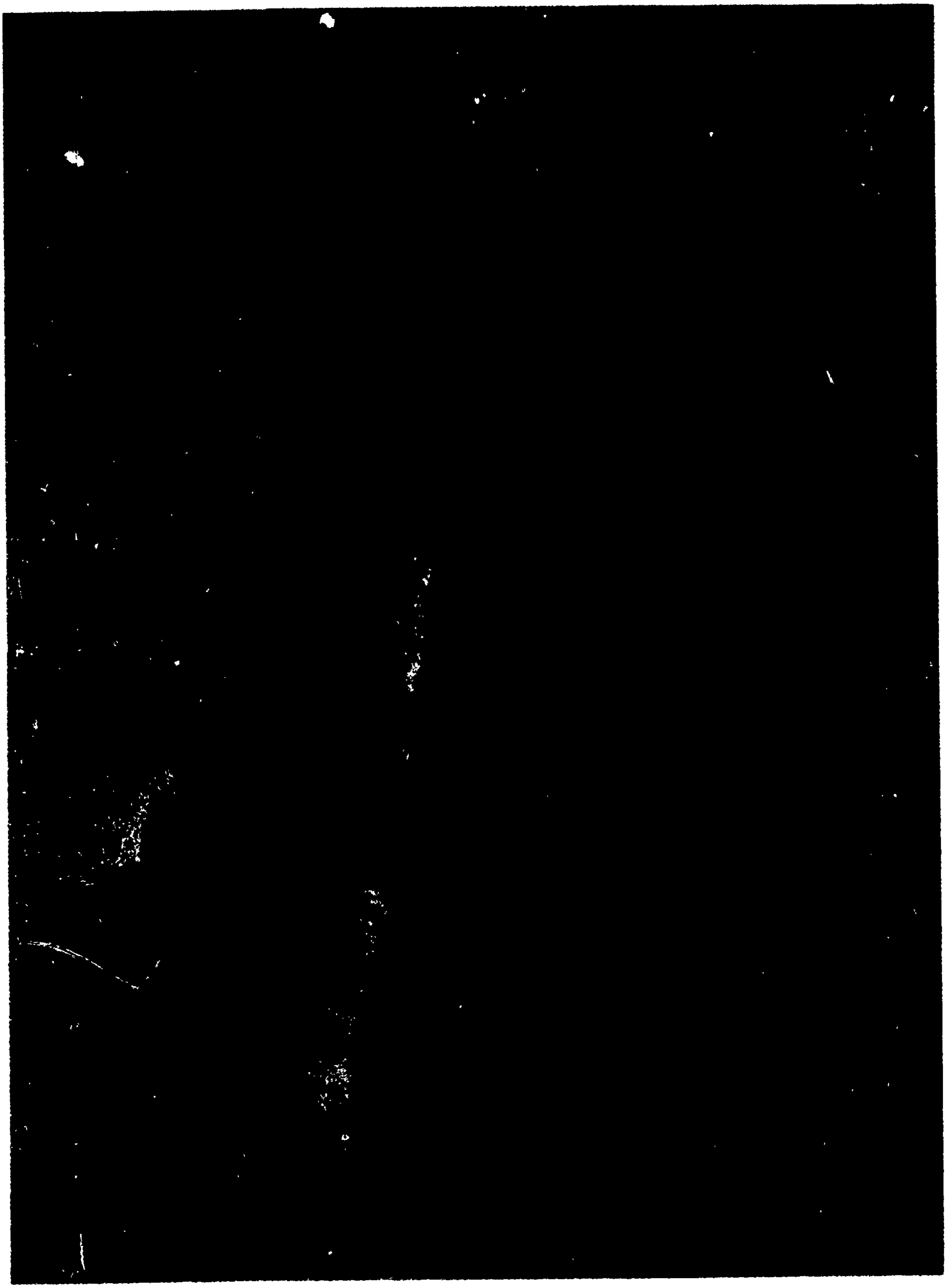

Figure 8-106. Upper Bearing Assembly (P - 25150I)

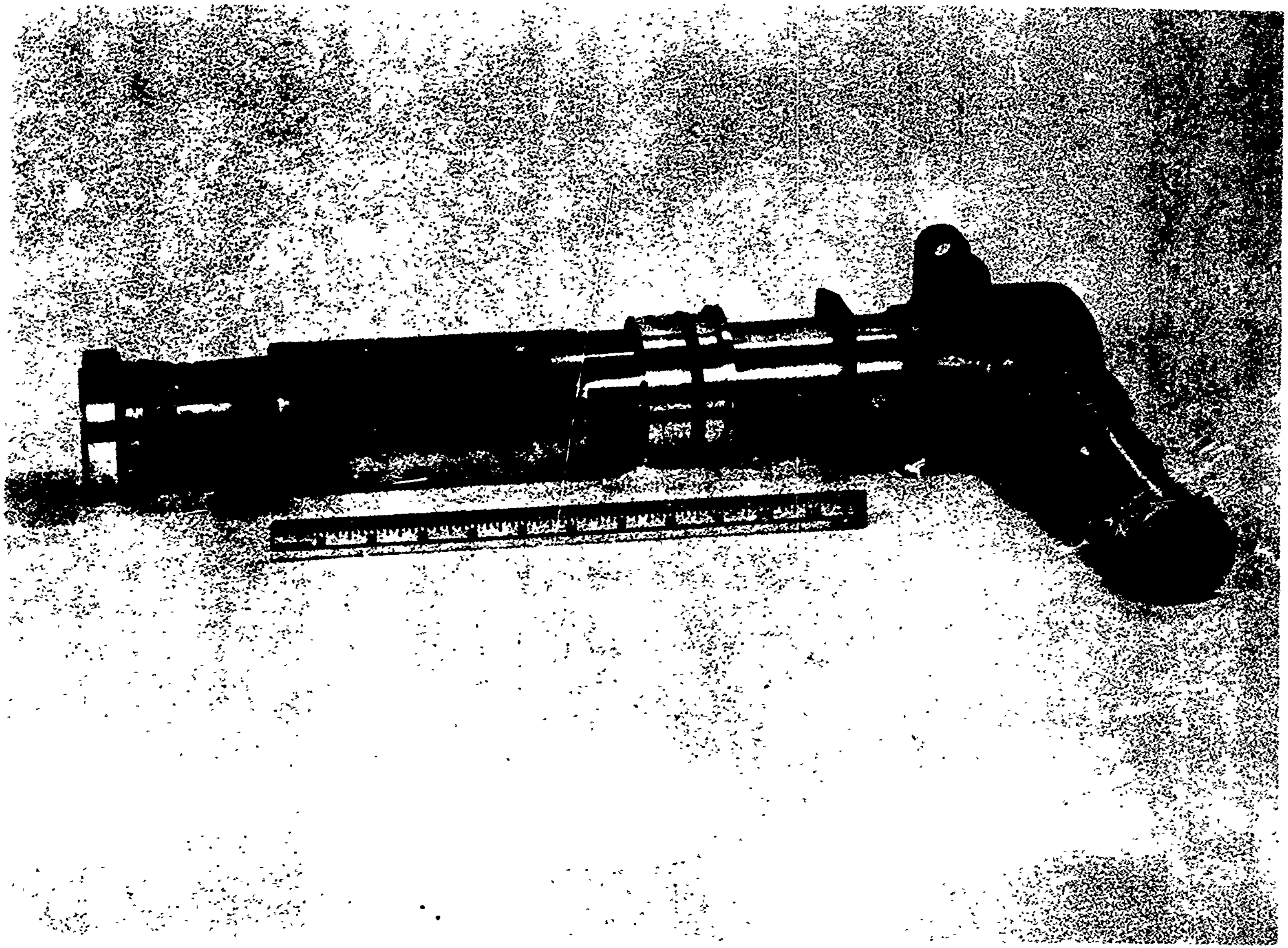

Figure 8-107. Completed Piston-Axle Assembly (P-25150R)

ELECTROFORMS, INC.
MATERIAL SPECIFICATION

TITLE: ELECTROFORMED METAL

WRITTEN BY: Paul Silverstone DATE WRITTEN: 7-18-56

CHECKED BY: Steven Silverstone DATE ISSUED: 7-18-56

I. Purpose

This specification covers the general requirements for molecular deposited metal such as nickel, copper, iron and silver and more specifically for metal deposited from an aqueous type bath using DC current.

II. Grade

The metal as deposited must be of grade suitable for airborne aircraft and missile complex shapes as determined by drawing and shall meet the requirements of this specification.

III. Types

The metal shall be specified as follows:

Grade I	Electroformed nickel medium strength (weldable)
Grade II	Electroformed nickel (nonweldable)
Grade III	Electroformed copper hard
Grade IV	Electroformed copper soft
Grade V	Electroformed nickel, hi strength (weldable)
Grade VI	Electroformed nickel, medium strength (weldable)
Grade VII	Electroformed silver
Grade VIII	Electroformed iron

IV. Quality

a. All parts manufactured per this specification shall be of uniform quality and condition, free from cracks, nonmetallic inclusion, porosity wrinkles except that any surface wrinkle, the depth of which is less than the thickness of metal wall is permissible.

b. Quality standards must meet the requirements of Federal Specification MIL-Q-9858A.

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V. Physical Properties

a. Composition

Grade I, V and VI	Minimum nickel content shall be 99.2 percent
Grade III	Minimum copper content shall be 99.9 percent
Grade IV	Minimum copper content shall be 99.9 percent
Grade VII	Minimum silver content shall be 99.9 percent
Grade VIII	Minimum iron content shall be 99.9 percent

b. Mechanical properties shall be as specified on the following table:

	Metal	Tensile Strength Lbs./Sq. Inch Minimum	Yield Strength Lbs./Sq. Inch Minimum	Elongation Percent Minimum	Deposit Stress
Grade I	Nickel	80,000	50,000	10	Tensile
Grade II	Nickel	200,000	150,000	1	Compressive
Grade III	Copper	50,000	25,000	10	
Grade IV	Copper	20,000	10,000	20	
Grade V	Nickel	160,000	100,000	2	Tensile
Grade VI	Nickel	100,000	70,000	8	Tensile
Grade VII	Silver				
Grade VIII	Iron				

VI. Methods of Testing

a. Mechanical properties shall be determined in accordance with the latest revision of Federal Specification QQ-M-151a except that gage length may be one inch.

b. Tensile tests shall be conducted on test specimens in accordance with good shop practice and with each batch of parts, or as specified by the customer.

VII. Dimensions and Tolerances

Dimensions and tolerances of parts made from electroformed metal shall be in accordance with drawing requirements.

VIII. Packaging

Packaging and marking shall be in accordance with customer requirements or E-221.

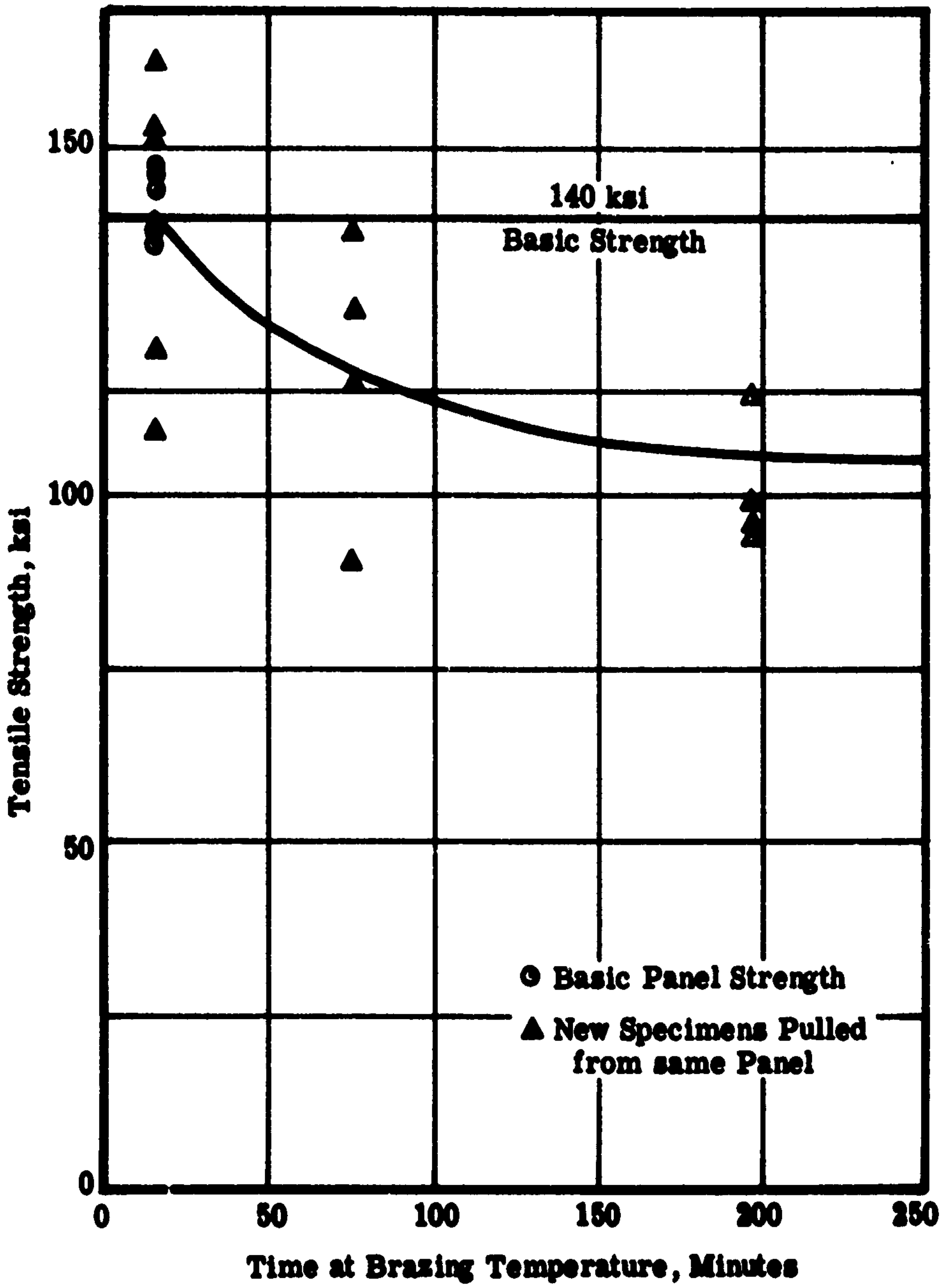

Figure A-1. Plot of Tensile Data Showing Effect of 1130° F Brazing Temperature on Strength of BORSIC-Aluminum Composite

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APPENDIX B

BORON-EPOXY TENSION AND COMPRESSION SPECIMENS

This discussion pertains to the derivation of the composite properties listed in Table 4-3.

Using company funds, and as part of a continuing in-house effort, Hercules conducted tests on specimens fabricated from the Boron/BP-907-104A system to obtain more accurate characterization of basic ply properties. These tests included the following:

- Longitudinal Compression
- Transverse Compression
- Longitudinal Tension
- Transverse Tension
- ±45° Cross-ply Tension

Compressive Properties

Sandwich beam tests were run to determine longitudinal and transverse compressive properties. The beam configuration was identical to that recommended by reference 6. At the time this information was supplied to Bendix, data reduction was complete on all of the longitudinal specimens and two of the transverse specimens. The average values from these tests are shown in Table B-2. In all five longitudinal tests, failure occurred at the loading pad; thus, the values shown for strength (338,600 psi) and strain (1.1 percent) are conservative. Failure of the transverse specimens occurred in the gage section.

Tensile Properties

Additional longitudinal tensile tests were run to better establish the reproducibility of the values. Two different broad good batches were tested - one wound at 216 fibers per inch and one at 230 fibers per inch. Although the use of two different fiber per inch values in obtaining reproducibility data may appear overly conservative, it is an attempt to include some variation since it probably exists in the fabricated part. Employing both sets of values, the data are shown in Table B-2. The standard deviations on strength and strain appear reasonable while the variation in modulus is high.

Additional tests were also run to establish reproducibility of transverse tensile values. A total of 15 tests were run employing three different batches of broadgoods in four different plates. The data are given in Table B-2. As in the tensile tests, the standard deviation of strength and strain are reasonable while the variation in modulus is high.

APPENDIX C

BORSIC-ALUMINUM PIN BEARING SPECIMENS

This discussion deals with the derivation of the pin bearing strengths listed in Table 4-4.

Pinned joints were explored for use in the BORSIC-aluminum side brace links and in the torque arm root lugs. One method of reinforcing the pin hole is by the application of ±45° cross ply inserts. Little information was published on the pin supporting strength for the diameter to width and edge distance ratios involved here. For purposes of obtaining such information, three specimens of the configuration shown in Figure C-1 were fabricated and tested. A tooling trial specimen was designated as PBA-0 and the two primary specimens as PBA-1 and PBA-2. Photographs of these specimens before testing are shown in Figures C-2 and C-3.

The specimens were loaded to rupture in a tension testing machine. Each specimen was first loaded through a pin at each end. After rupture of the weak end, the failed portion was held in a friction grip and reloaded until rupture of the second pinned end. The failed specimens are shown in Figure C-4.

A summary of the geometric parameters and the test results are given in Table D-1. Suffix -1 applied to the specimen number indicates the weaker end load. The suffix -2 indicates the stronger end load. The fabrication details associated with these specimens are discussed in Paragraph 8.1.2.

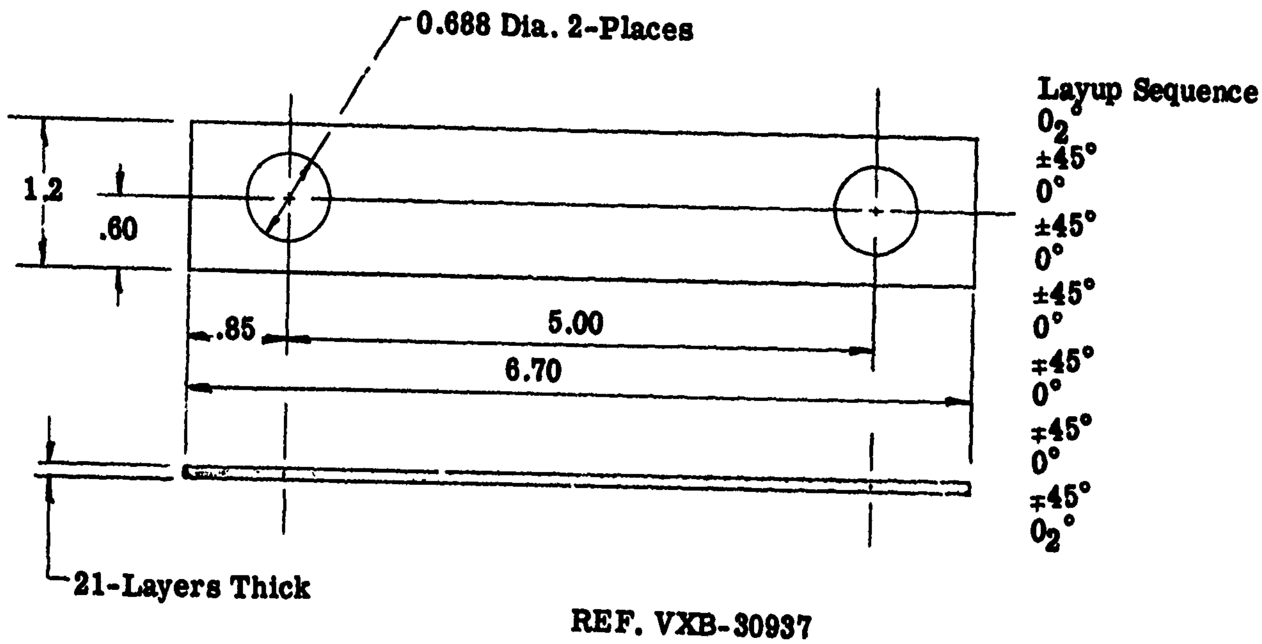

Figure C-1. BORSIC-Aluminum Pin Bearing Specimens PBA-1 and PBA-2

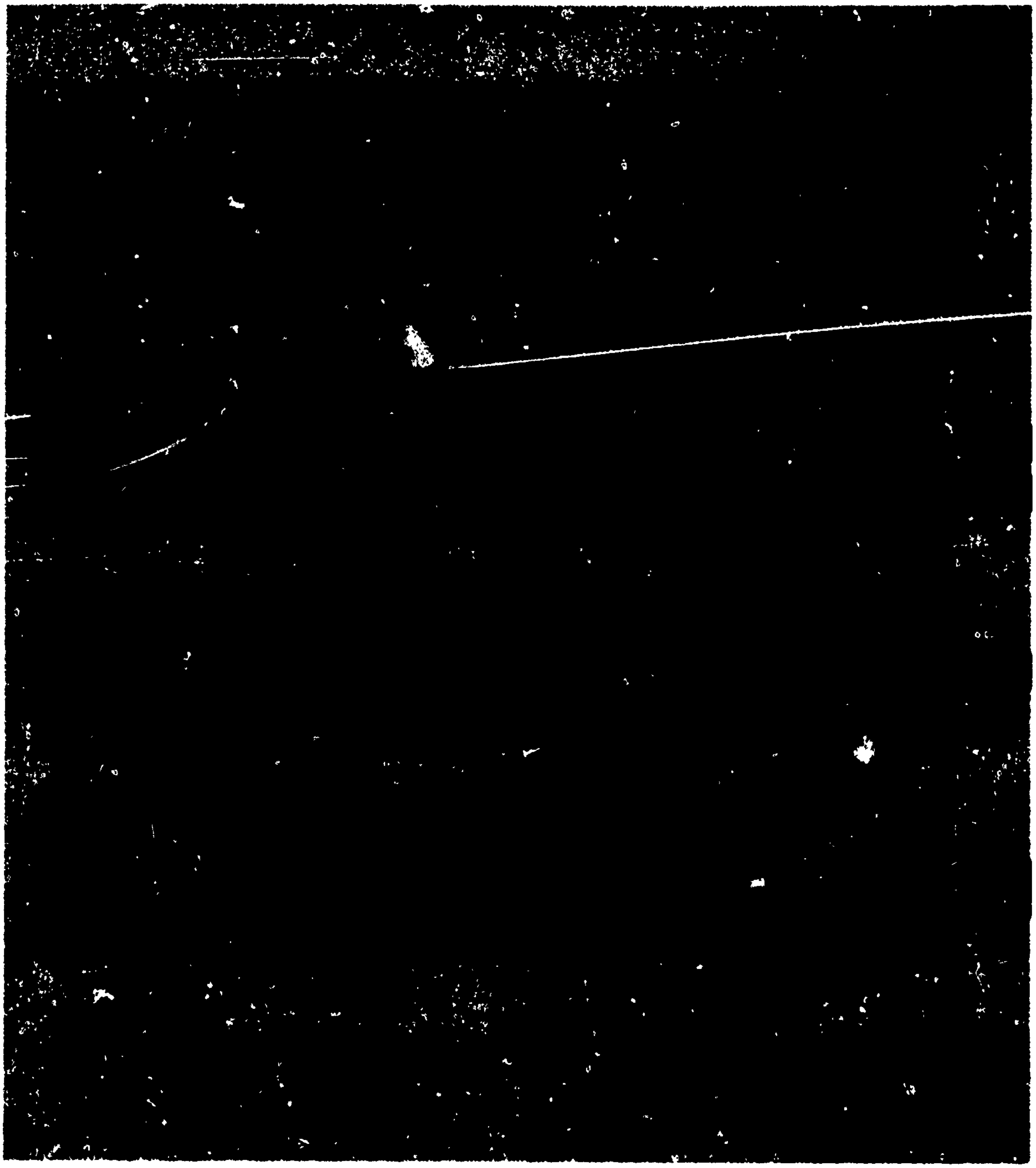

Figure C-3. Radiograph of BORSIC-Aluminum Pin Bearing Specimen (After Drilling)

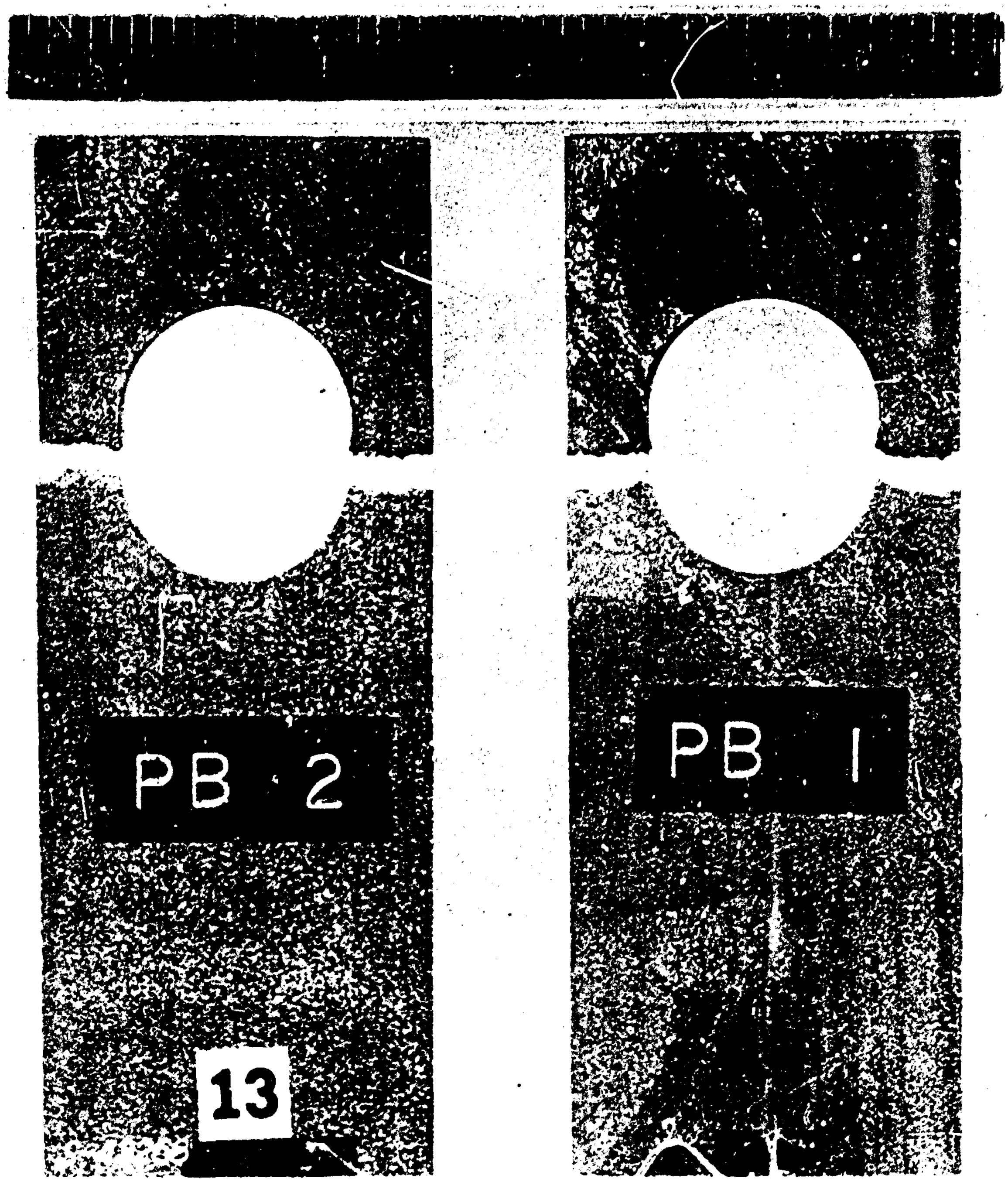

Figure C-4. Typical Failure Modes of BORSIC-Aluminum Specimens

APPENDIX D

BORON-EPOXY PIN BEARING SPECIMENS

This discussion deals with the derivation of the pin bearing strengths listed in Table 4-4.

Pinned joints were explored for use in the boron-epoxy side brace links and in the torque arm root lugs. One method of reinforcing the pin hole is by application of ±45° cross ply inserts. This program, however, has indicated the need for pin supporting strengths greater than available by the use of ±45° reinforcements. Spiral wound reinforcements have proven extremely effective in resisting stress concentrations around pin holes. Little information was available on the strength of this type of joint. For purposes of obtaining such information a number of specimens of the required configuration were built and tested. These specimens are shown in Figures D-1, D-2 and D-3. A total of five specimens were fabricated. The spiral reinforced specimens are designated PBE-0, PBE-1 and PBE-2, where PBE-0 is a tooling trial specimen. The ±45° layup specimens are designated as PBE-3 and PBE-4.

The specimens were loaded to rupture in a tension testing machine. Each specimen was first loaded through a pin at each end. After rupture of the weak end, the failed portion was held in a friction grip and reloaded until rupture of the second pinned end. The failed specimens are shown in Figures D-4 and D-5.

A summary of the geometric parameters and the test results are given in Table D-1. Suffix -1 applied to the specimen number indicates the weaker end load. The suffix -2 indicates the stronger end load.

The fabrication details associated with these specimens are discussed in Paragraph 8.2.2.

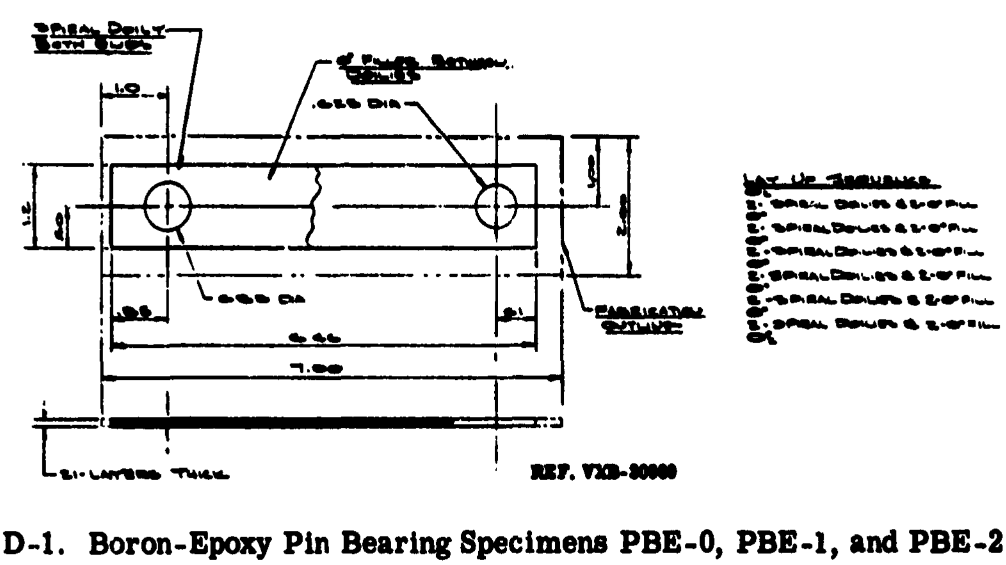

Figure D-1. Boron-Epoxy Pin Bearing Specimens PBE-0, PBE-1, and PBE-2

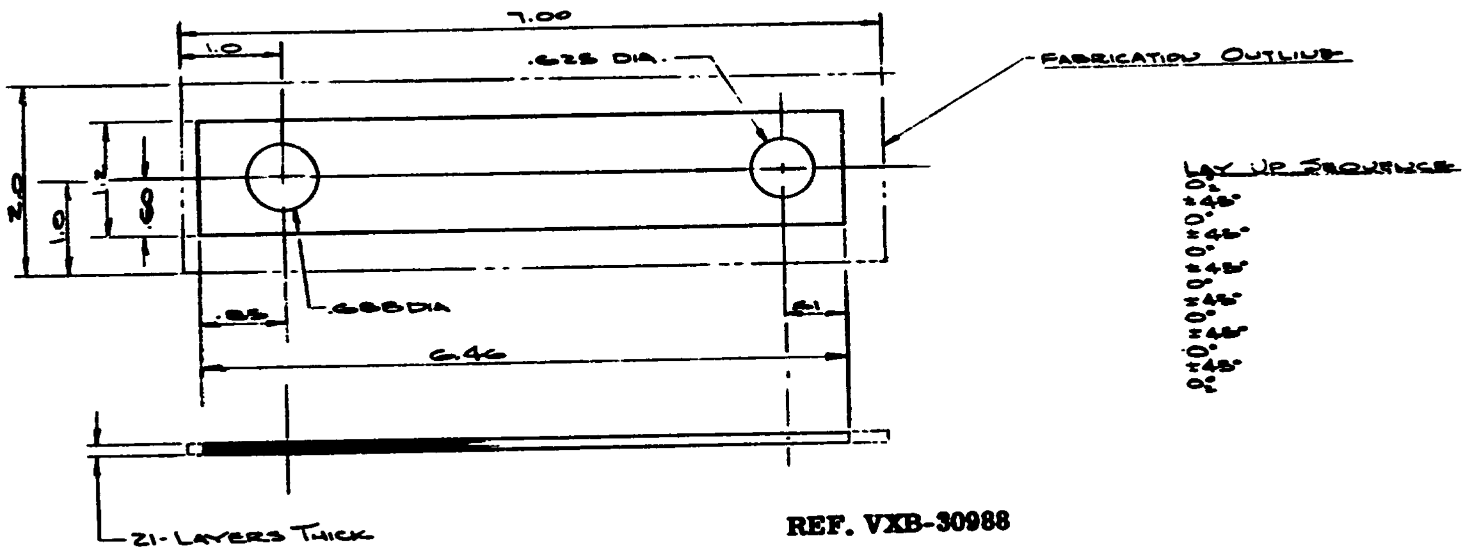

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Figure D-2. Boron-Epoxy Pin Bearing Specimens PBE-3 and PBE-4

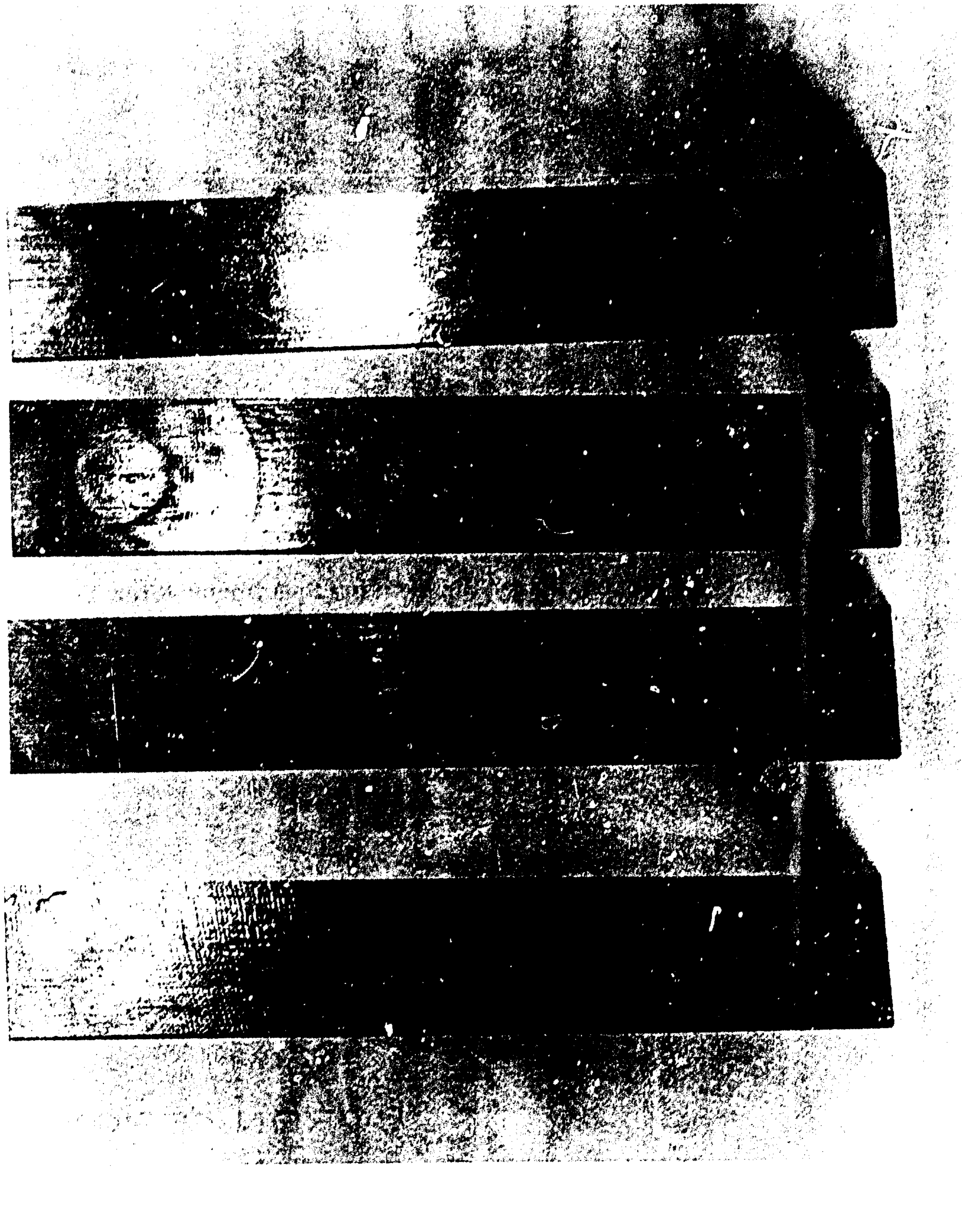


Figure D-3. Boron-Epoxy Specimens Before Machining

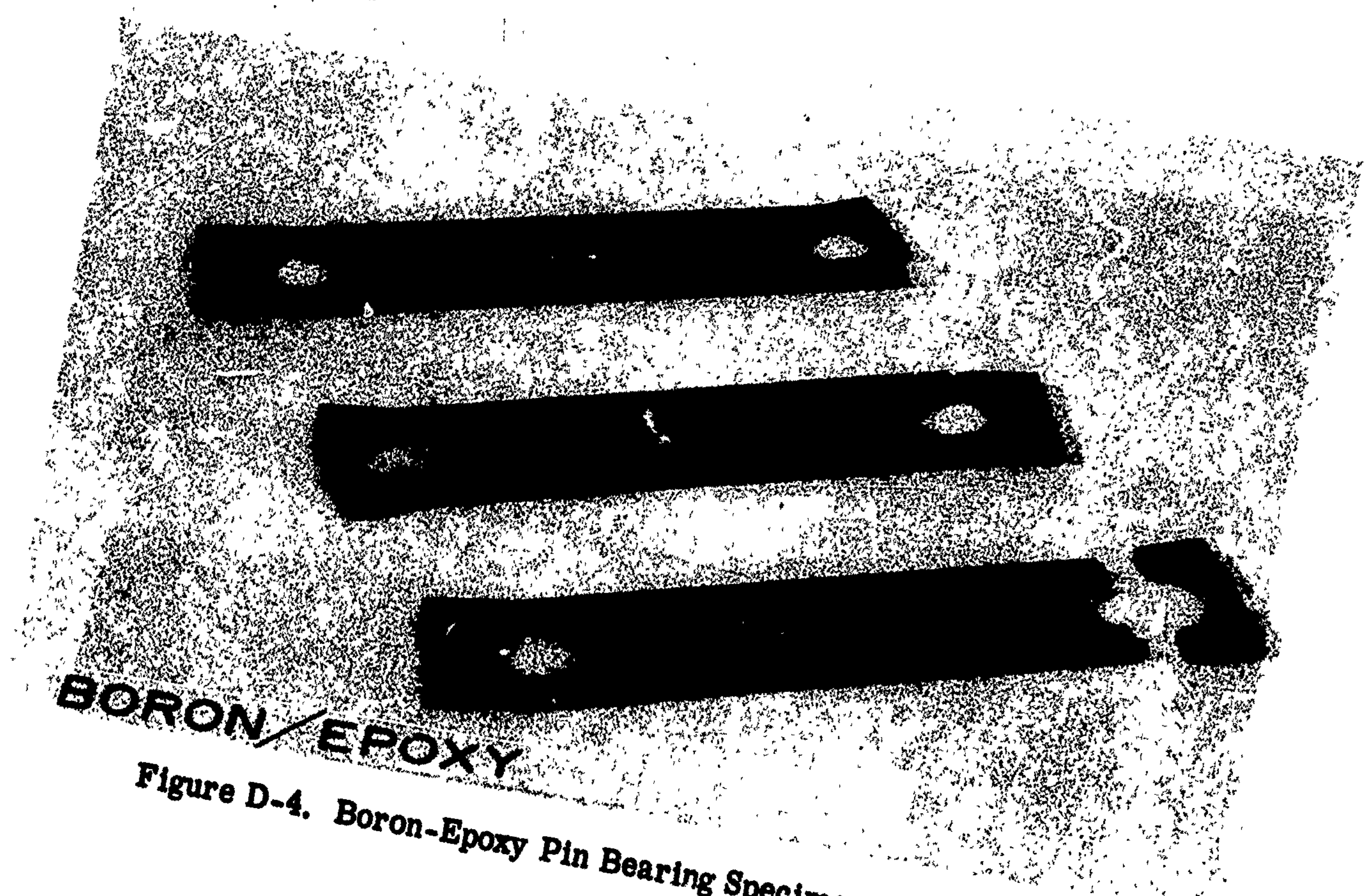


Figure D-4. Boron-Epoxy Pin Bearing Specimens After Test

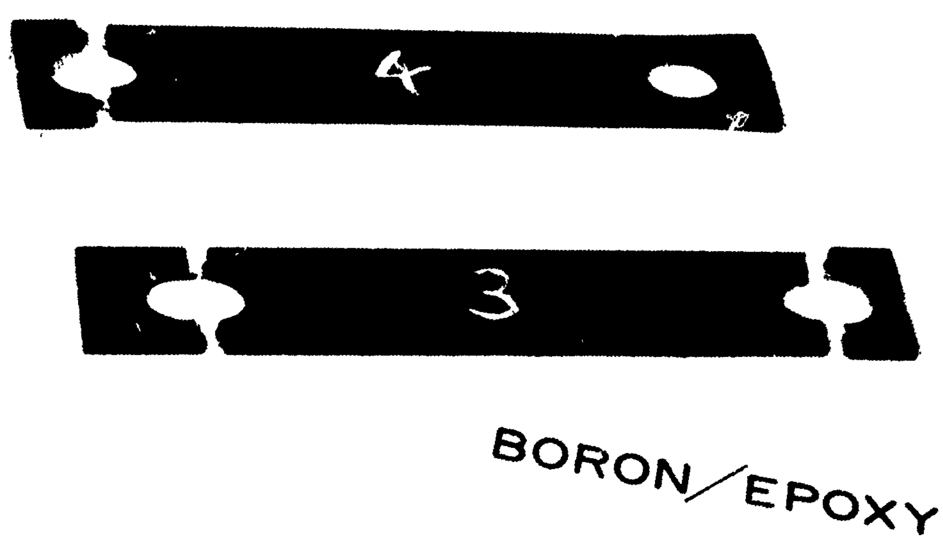


Figure D-5. Boron-Epoxy Pin Bearing Specimens After Test

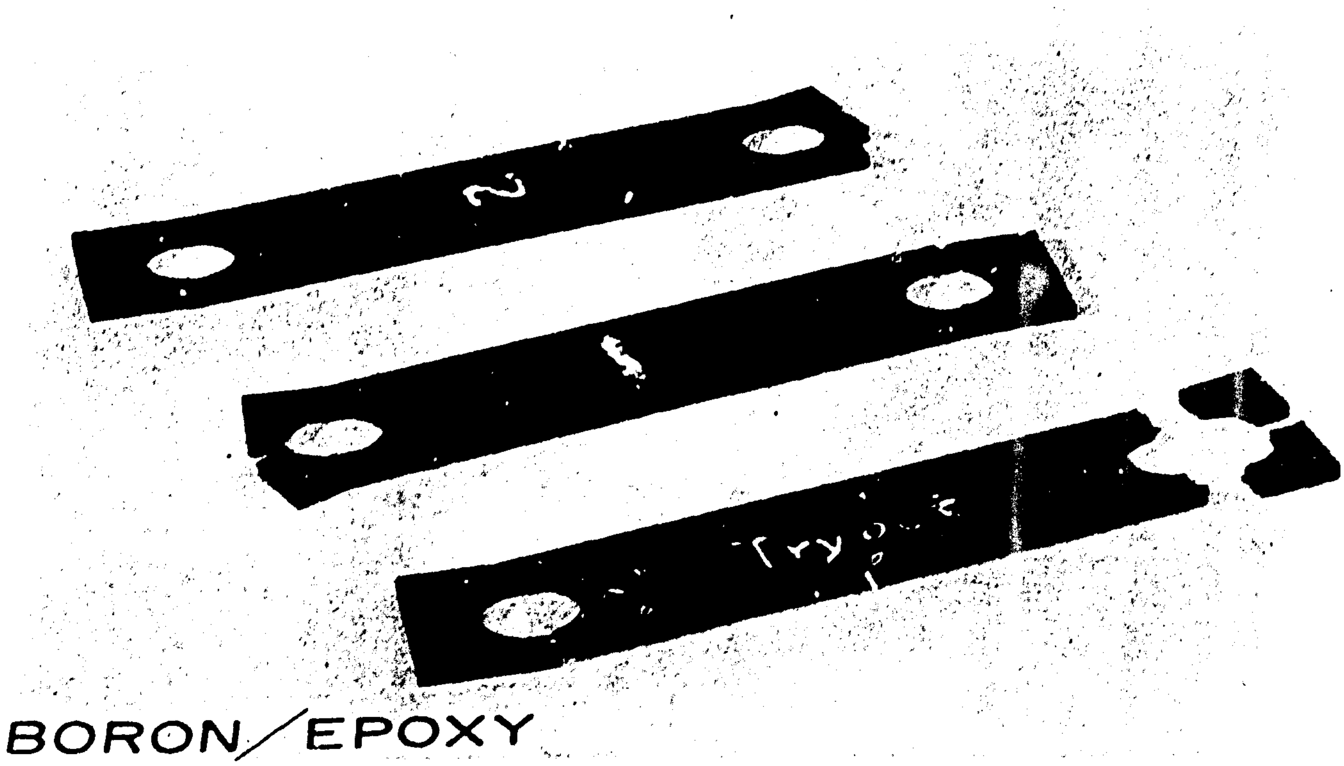


Figure D-4. Boron-Epoxy Pin Bearing Specimens After Test

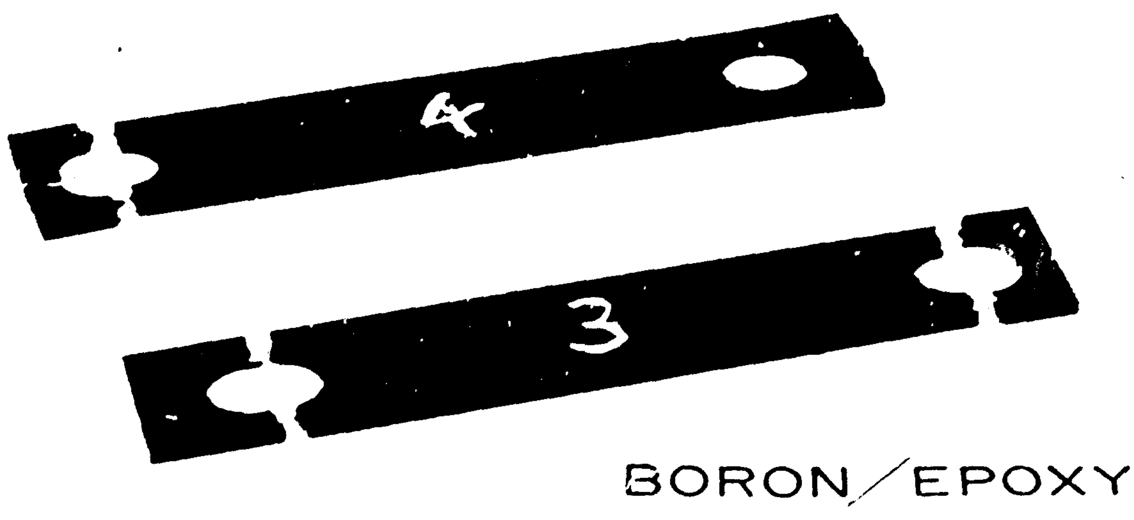
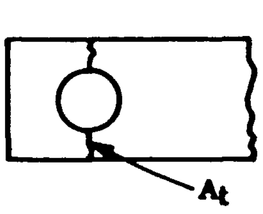


Figure D-5. Boron-Epoxy Pin Bearing Specimens After Test

TABLE D-1. SUMMARY OF PIN BEARING TESTS

Failure Modes

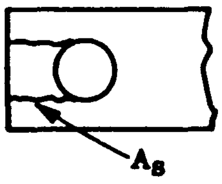
Tension = T



$A_t = (W-D)t$

$f_t = P/A_t$

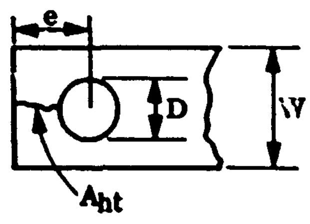
Shear = S



$A_s = 2\,et$

$f_s = P/A_s$

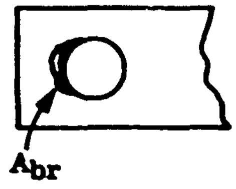
Hoop = H



$A_{ht} = (e-D/2)t$

$f_{ht} = \frac{P}{2A_{ht}}$

Bearing = B



$A_{br} = Dt$

$f_{br} = \frac{P}{A_{br}}$

Specimen No.	D in.	t in.	e in.	W in.	A_t in.^{2}	A_{ht} in.^{2}	A_s in.^{2}	A_{br} in.^{2}	Load lbs.	f_t ksi	f_{ht} ksi	f_s ksi	f_{br} ksi	Failure Mode
PBA-1-1	.688	.094	.850	1.196	.048	.048	.160	.065	1917	40.1	20.1	12.0	29.6	T
PBA-1-2	.688	.094	.850	1.196	.048	.048	.160	.065	1962	41.1	20.6	12.2	30.3	T
PBA-2-1	.688	.093	.850	1.185	.046	.047	.157	.064	1724	37.4	18.4	10.9	27.1	T
PBA-2-2	.688	.093	.850	1.185	.046	.047	.157	.064	1640 (1)	35.6	17.5	10.4	25.7	T
PBE-0-1	.625	.1035	.610	1.198	.059	.031	.126	.064	2535	42.7	41.2	20.1	39.2	H
PBE-0-2	.688	.1035	.853	1.198	.052	.052	.176	.071	4490	85.0	42.6	25.4	63.1	T
PBE-1-1	.625	.1035	.609	1.199	.099	.031	.125	.064	2880	48.4	47.1	22.8	44.5	H
PBE-1-2	.688	.1035	.855	1.199	.052	.052	.177	.071	4570	86.3	43.1	25.8	64.1	T
PBE-2-1	.625	.1055	.611	1.195	.060	.031	.128	.065	2930	48.7	46.6	22.7	44.4	S
PBE-2-2	.688	.1055	.853	1.195	.053	.053	.180	.072	4195	78.5	39.1	23.3	57.8	S
PBE-3-1	.625	.106	.610	1.20	.060	.031	.129	.066	1790	29.3	28.4	13.8	27.0	H
PBE-3-2	.688	.106	.854	1.20	.054	.054	.181	.072	3600	66.4	33.2	19.8	49.3	T
PBE-4-1	.625	.1045	.609	1.20	.059	.031	.127	.065	1645	30.8	29.8	14.5	28.2	H
PBE-4-2	.688	.1045	.852	1.20	.053	.053	.178	.071	3300	61.9	31.1	18.5	45.9	H

(1) Specimen slipped in grips prior to failure. PBA = BORSIC-Aluminum PBE = Boron-Epoxy

APPENDIX E

STRESS ANALYSIS ASSOCIATED WITH THE OUTER CYLINDER

This appendix consists of three sections:

E-1 Stress Analysis, Boron-Epoxy Cylinder Specimens

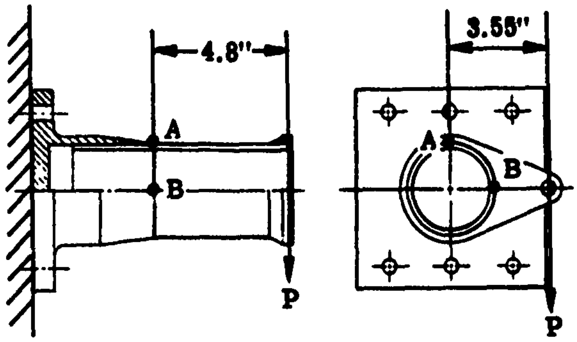
E-2 Design Analysis, Outer Cylinder Prototype

E-3 Strain Gage Analysis of Outer Cylinder

Appendix E-1

Stress Calculations, Boron-Epoxy Specimens

Item 1-Ten-Ply Cylinder, Paragraph 5.3.1.3.



Section Properties

OD = 2.912 in.	t = 0.050 in.	I = 0.459 in.^{4}
ID = 2.812 in.	A = 0.448 in.^{2}	I/c = 0.315 in.^{3}

Loads

P = 3800 pounds (rupture)
M = 3800 x 4.8 = 18,300 inch-pounds
T = 3800 x 3.55 = 13,500 inch-pounds

Stresses at A (Maximum Tension)

$$f_x = \frac{M}{I/c} = 18{,}300/0.315 = 53{,}000 \text{ psi}$$

$$f_{xy} = \frac{T}{2(I/c)} = 13{,}500/2(0.315) = 21{,}400 \text{ psi}$$

This stress combination plots as point A on the strength envelope below.

Stresses at B (Maximum Shear)

$$f_{xy1} = 21{,}400 \text{ psi (torsion)}$$

$$f_{xy2} = \frac{VQ}{Ib} = 2\frac{P}{A} = 2(3800)/0.448 = 17{,}000 \text{ psi}$$

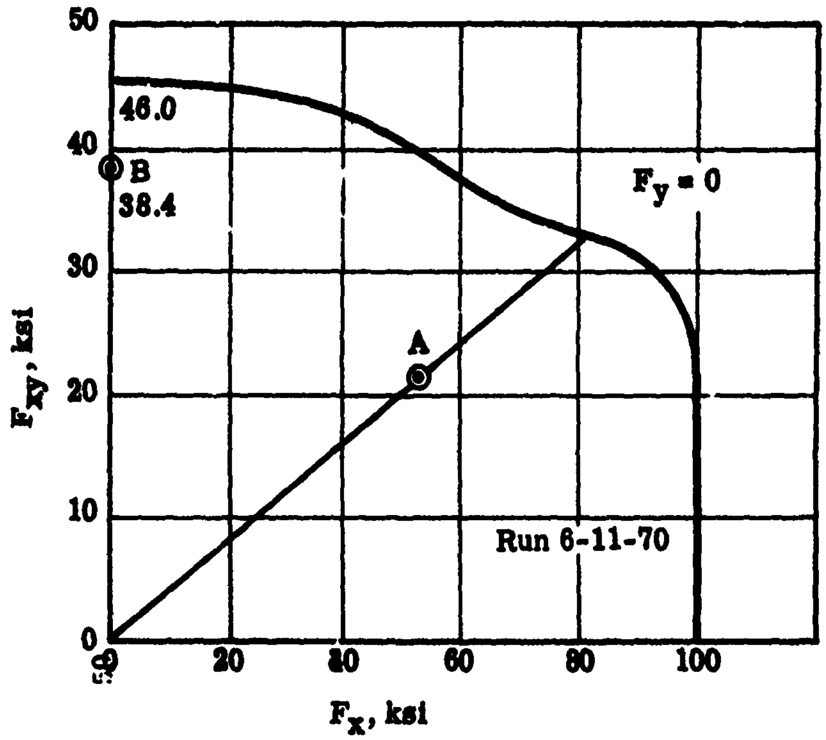
$$f_{xy} = 21{,}400 + 17{,}000 = 38{,}400 \text{ psi}$$

This stress plots as point B on the strength envelope on the following page.

Summary

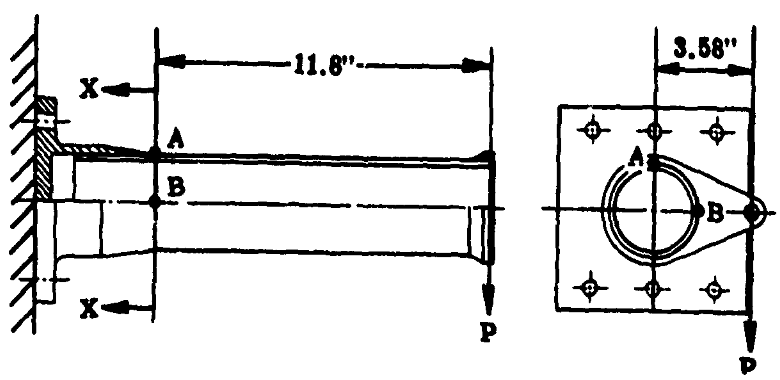
From the plot on the strength envelope, the critical region appears to be around point B on the tube. The tube ruptured at 38.4/46 = 0.84 of predicted strength. Difference may be due to local discontinuity effects where thin tube wall enters socket.

Predicted load = (46/38.4) 3800 = 4500 pounds.



Ultimate Strength Envelope Boron-Epoxy ($0_2°$, ±45°, 90°) Laminate

Item 2-Forty-Eight-Ply Cylinder, Paragraph 5.3.1.3.



Tube Strength at Section X-X:

Section Properties

OD = 3.32 in.	t = 0.254 in.	I = 2.892 $in.^4$
ID = 2.812 in.	A = 2.444 $in.^2$	I/c = 1.74 $in.^3$

Loads

P = 18,000 lbs. ultimate (design)
M = 18,000 x 11.8 = 212,000 in.-lbs.
T = 18,000 x 3.58 = 64,500 in.-lbs.

Stresses at A (Maximum Tension)

$$f_x = \frac{M}{I/c} = 212{,}000/1.74 = 122{,}000 \text{ psi}$$

$$f_{xy} = \frac{T}{2(I/c)} = 64{,}500/2(1.74) = 18{,}500 \text{ psi}$$

Plots as point A on the strength envelope below.

Stresses at B (Maximum Shear)

$$f_{xy1} = 18{,}500 \text{ (torsion)}$$

$$f_{xy2} = \frac{VQ}{Ib} = 2\frac{V}{A} = 2(18{,}000)/2.444 = 14{,}700 \text{ psi}$$

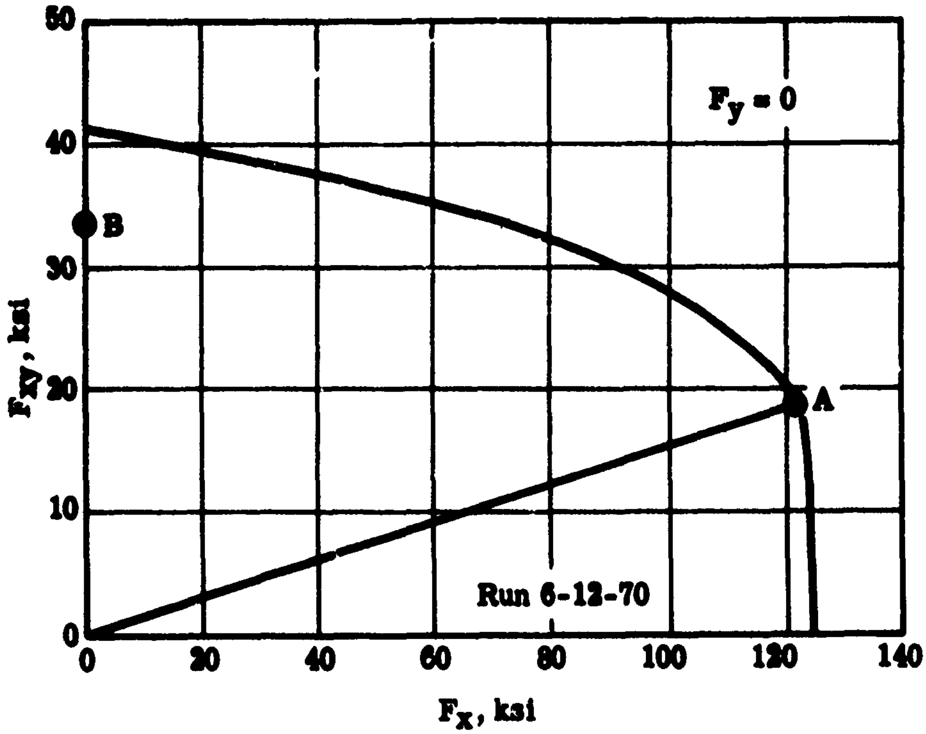
$$f_{xy} = 18{,}500 + 14{,}700 = 33{,}200 \text{ psi}$$

Plots as point B on the strength envelope below.

Load Applied in Test

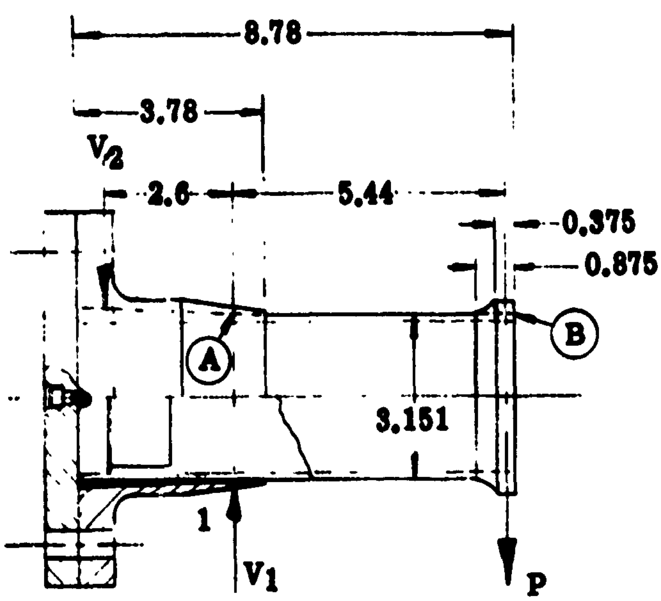
Maximum load achieved in test = 8760 pounds. (Failure did not occur in cylinder.)

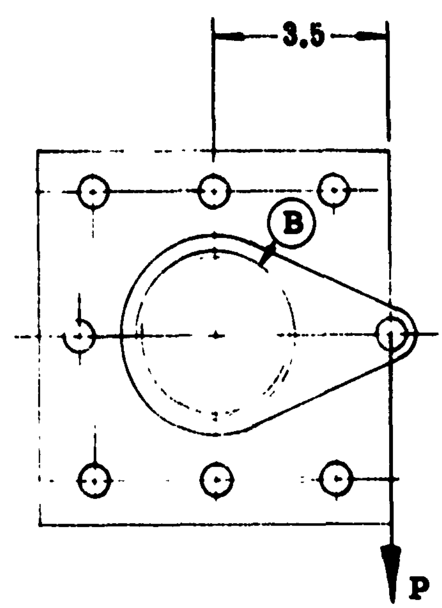
Percent of design load = $\frac{8760}{18000} \times 100 = 49$



Ultimate Strength Envelope Boron-Epoxy (0°_3, 90°, ±45°) Laminate

Item 3-Thirty-Two Ply-Cylinder, Paragraph 5.3.1.3.





A number of failure modes were investigated. The following calculations pertain to the two modes which indicate the lowest failure loads.

1. Circumferential Shear at (B) Between Loading Lug and Cylinder

Torque = T = 3.5P

Tangential Force = F = T/(D/2) = 2T/D

= 2(3.5P)/3.151 = 2.22P

Shear Area = A = πDt = 3.151π (0.875) = 8.75 in^2

Shear Stress = F/A = 2.22P/8.75 = 0.254P

Allowable Shear = F_{su} = 3360 psi ult (obtained from test on forty-eight-ply cylinder)

0.254P = 3360

P = 13000 lbs. ult.

2. Rupture of Tubewall at (A) Due to Combined Bending and Torsion.

Bending moment M is assumed to peak at the internal bearing reaction between the cylinder and socket. The resultant bearing reaction V_1 is assumed to occur at the one-third points of the socket length. By trial and error the rupture load was determined to be 15000 pounds.

M = 5.44P = 5.44(15000) = 81500 in.lbs.

T = 3.5 (15000) = 52500 in.lbs.

Section properties of cylinder.

OD = 3.15 ID = 2.81

I/c = 1.13

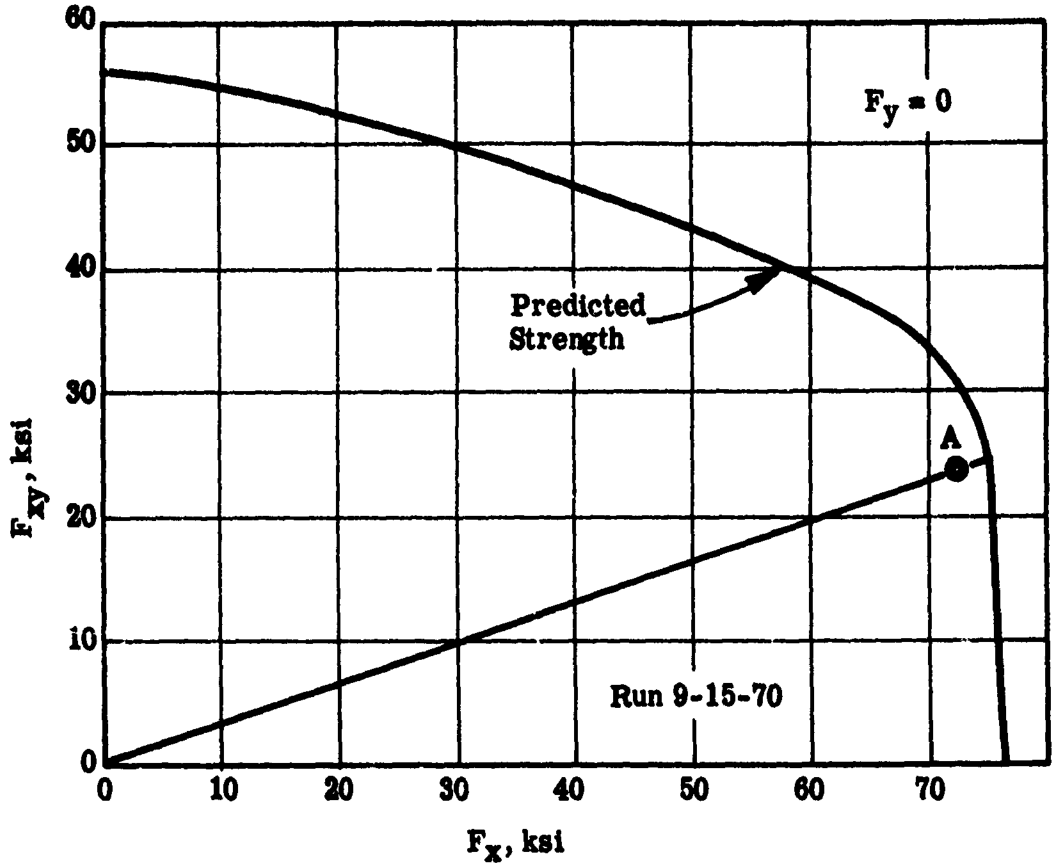
Bending Stress = f_x = M/(I/c) = 81500/1.13

= 72100 psi (normal)

Torsion Stress = f_{xy} = T/2(I/c) = 52500/2.26

= 23200 psi (shear)

This plots as point A on the strength envelope on the following page.



Ultimate Strength Envelope Boron-Epoxy (0°, 90°, ±45°) Laminate

Appendix E-2

Stress Calculations, Boron-Epoxy Outer Cylinder

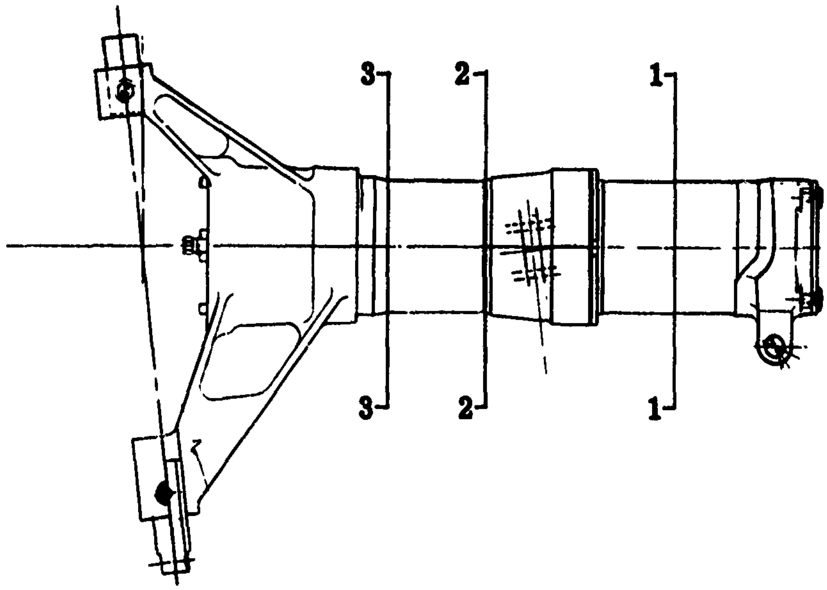


Figure E-1.

The cylinder soctions refer to those labelled above. The internal cross section loads were derived from the external loads shown in Table 4-1.

ULTIMATE LOADS					
Cylinder Sections	Load Condition Table 4-1	Bending Moment, in.-lbs.	Axial Tension lbs.	Torsion, in.-lbs.	Shear lbs.
1	2A	29,000		72,000	19,500
2	5A	174,000	6,000	69,000	19,000
3	5A	228,000	6,000	69,000	19,000

SECTION PROPERTIES						
Section	OD in.	ID in.	t in.	A $in.^2$	I $in.^4$	I/c $in.^3$
1,2	3.65	3.27	0.190	2.07	3.10	1.70
3	3.71	3.27	0.220	2.41	3.69	1.99

Section 1-1

Torsion $$f_{st} = \frac{T}{2(I/c)} = \frac{72000}{2(1.70)} = 21000 \text{ psi}$$

Shear $$f_s = \frac{VQ}{Ib} = \frac{2V}{A} = \frac{2(19500)}{2.07} = 19000 \text{ psi}$$

Maximum Shear $$f_{xy} = 21000 + 19000 = 40000 \text{ psi}$$

Pressure $$f_{tp} = \text{Negligible}$$

Point A on Figure E-2.

$$MS = \frac{42}{40} - 1 = 0.05$$

Section 2-2

Bending $$f_b = \frac{M}{I/c} = \frac{174{,}000}{1.70} = 102{,}000 \text{ psi}$$

Axial $$f_t = \frac{P}{A} = \frac{6000}{2.07} = 3000 \text{ psi}$$

Maximum Axial $$f_x = 102{,}000 + 3000 = 105{,}000 \text{ psi}$$

Torsion $$f_{st} = \frac{T}{2(I/c)} = \frac{69{,}000}{2(1.70)} = 20{,}000 \text{ psi}$$

$$f_{xy} = 20{,}000 \text{ psi}$$

Plots as point B on Figure E-2.

$$MS = \frac{116}{105} - 1 = 0.10$$

Section 3-3

Bending $$f_b = \frac{228{,}000}{1.99} = 115{,}000 \text{ psi}$$

Axial $$f_t = \frac{6000}{2.41} = 2000 \text{ psi}$$

Maximum Axial $$f_x = 115{,}000 + 2000 = 117{,}000 \text{ psi}$$

Torsion $$f_{st} = \frac{69{,}000}{2(1.99)} = 17{,}000 \text{ psi}$$

$$f_{xy} = 17{,}000 \text{ psi}$$

Plots as point C, Figure E-2

$$MS = \frac{122}{117} - 1 = 0.04$$

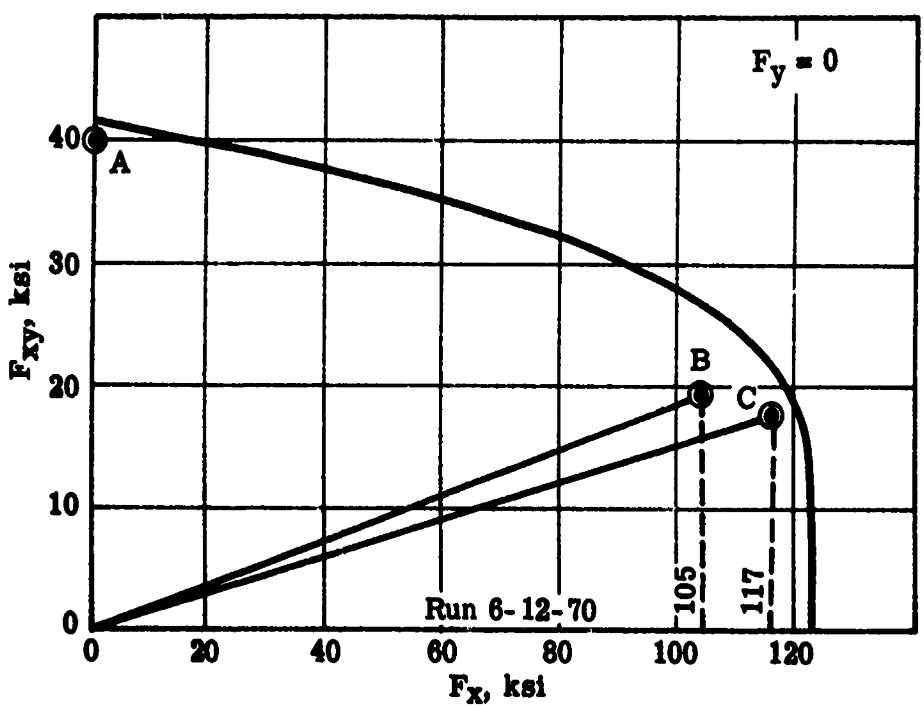
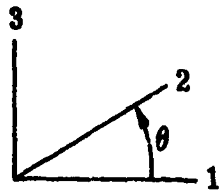


Figure E-2. Ultimate Strength Envelope Boron-Epoxy ($0_3°$, 90°, ±45°) Laminate

Appendix E-3

Strain Gage Analysis of Outer Cylinder

1. Basic Strain Gage Theory



Rectangular

Strain Elements

$$\epsilon_\theta = \frac{\epsilon_1 + \epsilon_3}{2} + \frac{\epsilon_1 - \epsilon_3}{2} \cos 2\theta + \frac{\gamma_{12}}{2} \sin 2\theta$$

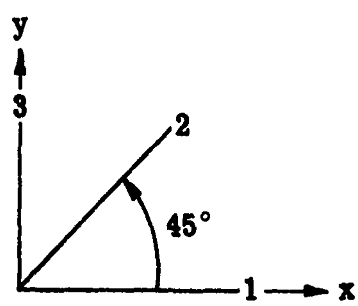
$$\theta = 45°$$

$$\epsilon_2 = \frac{\epsilon_1 + \epsilon_3}{2} + \frac{\gamma_{13}}{2}$$

$$2\epsilon_2 = \epsilon_1 + \epsilon_3 + \gamma_{13}$$

$$\gamma_{13} = 2\epsilon_2 - (\epsilon_1 + \epsilon_3)$$

Assume gages oriented on the composite material as shown below where the x-y axes coincide with the axes of orthotropic symmetry of the composite.



Now

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{33} \end{bmatrix} \begin{Bmatrix} \epsilon_x \\ \epsilon_y \\ \gamma_{xy} \end{Bmatrix}$$

where

$$Q_{11} = \frac{E_{xx}}{\left(1-\mu_{xy}\,\mu_{yx}\right)} \qquad Q_{12} = \frac{\mu_{xy}\,E_{xx}}{1-\mu_{xy}\,\mu_{yx}} \qquad \mu_{yx} = \mu_{xy}\frac{E_{yy}}{E_{xx}}$$

$$Q_{22} = \frac{E_{yy}}{1-\mu_{xy}\,\mu_{yx}} \qquad Q_{33} = G_{xy}$$

The above equation may be solved for the stresses by letting

$$\epsilon_x = \epsilon_1$$

$$\epsilon_y = \epsilon_3$$

$$\gamma_{xy} = \gamma_{13} = 2\,\epsilon_2 - (\epsilon_1 + \epsilon_3)$$

2. Strain Gage Application

Strain gages were applied to the outer cylinder at the locations identified in Figure E-3. The individual elements of each rosette were wired up to a BLH Model 160 Strain Gage Scanner. The readout was fed into an IBM Model 526 Card Punch. Calculation of the stresses was accomplished by computer using the punched cards as input. The results are displayed in Tables E-1, E-2 and E-3.

3. Strain Gage Results

f_x, f_y, f_{xy} - stresses calculated from statics

$\sigma_x, \sigma_y, \sigma_{xy}$ - stresses calculated from strain measurements

Keeping in mind inadvertent 90 degree rotation of rosette, Figure E-3,

$$\sigma_x \sim f_y, \quad \sigma_y \sim f_x, \quad \sigma_{xy} \sim f_{yx}$$

As typical examples, some of the higher strain values are considered.

Loading Condition P_{rb} (Reference Table 7-1)

(a) Results from Strain Measurements

Highest numerical values were obtained with Rosettes 1 and 7. Two runs were made for this load condition, Tables E-1 and E-2. The results are plotted in Figures E-4 and E-5.

(b) **Results from Statics**

Rosettes 1 and 7 coincide with Section 3-3, Figure E-1.

Assume a value of $P_{rb} = P_0 = 3.0$ kips

P_{rb} ultimate = 1.5 x 9.0 = 13.5 kip (Paragraph 7.2.2.1)

$P_0 = 3/13.5 = 0.222\ P_{rb}$ ultimate

Correction for torsion load due to wheel offset.

- Wheel offset static analysis = 7.5 in. (Figure 4-1)
- Wheel offset test rig = 7.0 in. (Figure 7-9)
- Correction for torsion = 7/7.5 = .93

Using design stresses from Appendix E-2:

Rosette 1

$f_x = .222\ (115000 + 2000) = 26000$ psi

$f_{xy} = .222 \times .93 \times 17000 = 3500$ psi

These plotted as points A and B on Figure E-4.

Rosette 7

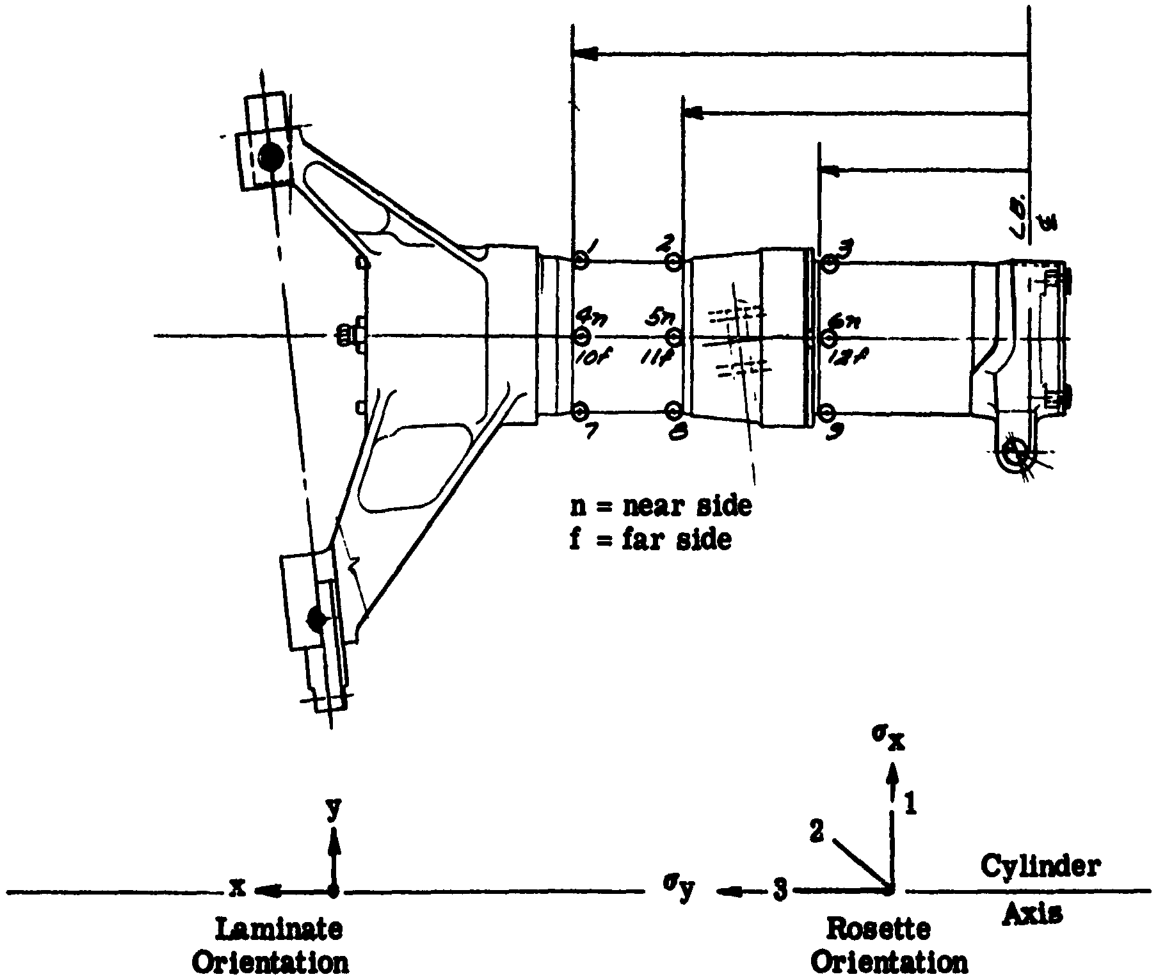
$f_x = .222\ (-115000 + 2000) = 25000$ psi

$f_{xy} = .222 \times .93 \times 17000 = 3500$ psi

These plotted as points A and B, Figure E-5.

Loading Condition P_{dr} (Reference Table 7-1)

Strain rosette data fro the P_{dr} condition is given in Table E-3.



Rosettes inadvertently
rotated 90 degrees from
required orientation.

Figure E-3. Outer Cylinder Strain Gage Locations

TABLE E-1. STRAIN GAGE RESULTS, P_{rb}, RUN 1 (SHEET 1 OF 4)

COMPUTER PROGRAM NO. 870-31 DATED: 11-2-1971 R. A. RIDHA RUN DATE: 11/15/71

CONVERSION OF STRAIN ROSETTE READINGS TO STRESSES *IN ORTHOTROPIC MATERIALS*

A-37 LANDING GEAR RUN#1 11-12-1971

**MATERIAL PROPERTIES

EXX= 9299.398 EYY= 17963.098 GXY= 3241.100 MUXY= 0.1559 MUYX= 0.3011

THE C-MATRIX

9757.5	2936.4	0.0
2936.4	18848.0	0.0
0.0	0.0	3241.1

LOAD CALIBRATION FACTOR: 570.000 MICRO IN./KIP. NUMBER OF ROSETTES: 12

TRANSDUCER READING: 2 APPLIED LOAD: 0.004 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	0.000014	0.000019	0.000032	-0.000008	0.231	0.644	-0.026
2	43	44	45	-0.000001	-0.000003	0.000026	-0.000031	0.067	0.487	-0.100
3	46	47	48	0.000004	0.000003	0.000031	-0.000029	0.130	0.596	-0.094
4	50	51	52	0.000029	0.000025	0.000027	-0.000006	0.362	0.594	-0.019
5	53	54	55	0.000004	0.000008	0.000007	0.000005	0.060	0.144	0.016
6	56	57	58	0.000002	0.000005	0.000009	-0.000001	0.046	0.176	-0.003
7	60	61	62	0.000044	0.0	-0.000010	-0.000034	0.400	-0.059	-0.110
8	63	64	65	0.000007	-0.000013	-0.000018	-0.000015	0.015	-0.319	-0.049
9	66	67	68	0.000007	0.000001	-0.000005	-0.000000	0.054	-0.074	-0.000
10	80	81	82	0.000042	0.000010	0.0	-0.000022	0.410	0.123	-0.071
11	83	84	85	0.000015	-0.000009	-0.000009	-0.000024	0.120	-0.126	-0.078
12	86	87	88	-0.000009	-0.000032	-0.000024	-0.000031	-0.156	-0.479	-0.100

TABLE E-1. STRAIN GAGE RESULTS, P_{rb}, RUN 1 (SHEET 2 OF 4)

TRANSDUCER READING: 247 APPLIED LOAD: 0.433 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000027	0.000027	0.000243	-0.000162	0.451	4.501	-0.525
2	43	44	45	-0.000046	-0.000040	0.000179	-0.000213	0.077	3.239	-0.690
3	46	47	48	-0.000056	-0.000034	0.000160	-0.000172	-0.076	2.851	-0.557
4	50	51	52	0.000015	0.000014	0.000048	-0.000035	0.287	0.949	-0.113
5	53	54	55	-0.000004	0.000004	0.000017	-0.000005	0.011	0.309	-0.016
6	56	57	58	-0.000004	-0.000016	-0.000001	-0.000027	-0.042	-0.031	-0.088
7	60	61	62	0.000045	-0.000166	-0.000198	-0.000179	-0.143	-3.600	-0.580
8	63	64	65	0.000024	-0.000161	-0.000163	-0.000183	-0.245	-3.002	-0.593
9	66	67	68	-0.000013	-0.000134	-0.000083	-0.000172	-0.371	-1.603	-0.557
10	80	81	82	0.000058	-0.000114	0.000028	-0.000314	0.648	0.698	-1.019
11	83	84	85	0.000073	-0.000137	-0.000068	-0.000279	0.512	-1.067	-0.904
12	86	87	88	-0.000016	-0.000177	-0.000017	-0.000321	-0.206	-0.367	-1.040

TRANSDUCER READING: 505 APPLIED LOAD: 0.886 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000086	0.000045	0.000481	-0.000305	0.574	8.813	-0.989
2	43	44	45	-0.000093	-0.000060	0.000361	-0.000398	0.153	6.531	-1.256
3	46	47	48	-0.000103	-0.000056	0.000318	-0.000327	-0.071	5.691	-1.060
4	50	51	52	0.000041	0.000039	0.000104	-0.000067	0.706	2.081	-0.217
	53	54	55	0.000001	0.000022	0.000057	-0.000014	0.177	1.077	-0.045
6	56	57	58	-0.000003	-0.000028	0.000001	-0.000054	-0.026	0.010	-0.175
7	60	61	62	0.000041	-0.000345	-0.000412	-0.000339	-0.615	-7.586	-1.099
8	63	64	65	0.000036	-0.000324	-0.000343	-0.000341	-0.657	-6.359	-1.105
9	66	67	68	-0.000029	-0.000271	-0.000183	-0.000330	-0.821	-3.534	-1.070
10	80	81	82	0.000078	-0.000244	0.000057	-0.000623	0.929	1.304	-2.019
11	83	84	85	0.000138	-0.000282	-0.000148	-0.000554	0.912	-2.384	-1.796
12	86	87	88	-0.000043	-0.000369	-0.000050	-0.000645	-0.566	-1.069	-2.091

TABLE E-1. STRAIN GAGE RESULTS, P_{rb}, RUN 1 (SHEET 3 OF 4)

TRANSDUCER READING: 756 APPLIED LOAD: 1.326 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000136	0.000075	0.000724	-0.000436	0.800	13.246	-1.420
2	43	44	45	-0.000129	-0.000070	0.000546	-0.000557	0.346	9.912	-1.505
3	46	47	48	-0.000189	-0.000102	0.000412	-0.000427	-0.634	7.210	-1.384
4	50	51	52	0.000025	0.000083	0.000175	-0.000034	0.756	3.372	-0.110
5	53	54	55	0.000016	0.000058	0.000113	-0.000013	0.486	2.177	-0.042
6	56	57	58	0.0	-0.000028	0.0	-0.000056	0.0	0.0	-0.182
7	60	61	62	0.000075	-0.000522	-0.000628	-0.000491	-1.113	-11.616	-1.591
8	63	64	65	0.000062	-0.000475	-0.000516	-0.000496	-0.911	-9.543	-1.603
9	66	67	68	-0.000031	-0.000392	-0.000262	-0.000491	-1.072	-5.029	-1.591
10	80	81	82	0.000127	-0.000349	0.000101	-0.000926	1.536	2.277	-3.001
11	83	84	85	0.000224	-0.000406	-0.000207	-0.000829	1.577	-3.243	-2.667
12	86	87	88	-0.000062	-0.000570	-0.000061	-0.001017	-0.784	-1.332	-3.296

TRANSDUCER READING: 1010 APPLIED LOAD: 1.772 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000220	0.000075	0.000934	-0.000564	0.598	16.458	-1.628
2	43	44	45	-0.000207	-0.000110	0.000707	-0.000720	0.058	12.717	-2.334
3	46	47	48	-0.000296	-0.000150	0.000536	-0.000540	-1.313	9.233	-1.753
4	50	51	52	0.000023	0.000107	0.000229	-0.000038	0.697	4.384	-0.123
5	53	54	55	0.000013	0.000074	0.000149	-0.000014	0.565	2.847	-0.045
6	56	57	58	-0.000009	-0.000035	-0.000008	-0.000053	-0.111	-0.177	-0.172
7	60	61	62	0.000071	-0.000716	-0.000870	-0.000633	-1.864	-16.169	-2.052
8	63	64	65	0.000064	-0.000641	-0.000710	-0.000636	-1.462	-13.194	-2.061
9	66	67	68	-0.000054	-0.000534	-0.000360	-0.000654	-1.585	-6.944	-2.129
10	80	81	82	0.000157	-0.000470	0.000125	-0.001222	1.893	2.817	-3.961
11	83	84	85	0.000295	-0.000541	-0.000284	-0.001093	2.044	-4.436	-3.543
12	86	87	88	-0.000093	-0.000777	-0.000099	-0.001362	-1.196	-2.139	-4.414

TABLE E-1. STRAIN GAGE RESULTS, P_{rb}, RUN 1 (SHEET 4 OF 4)

TRANSDUCER READING: 1261 APPLIED LOAD: 2.212 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000274	0.000099	0.001162	-0.000690	0.741	21.096	-2.235
2	43	44	45	-0.000266	-0.000141	0.000861	-0.000877	-0.066	15.446	-2.642
3	46	47	48	-0.000359	-0.000183	0.000683	-0.000690	-1.496	11.818	-2.236
4	50	51	52	0.000050	0.000155	0.000307	-0.000047	1.390	5.933	-0.152
5	53	54	55	0.000030	0.000108	0.000210	-0.000024	0.910	4.046	-0.078
6	56	57	58	-0.000007	-0.000030	-0.000010	-0.000043	-0.098	-0.209	-0.139
7	60	61	62	0.000082	-0.000888	-0.001092	-0.000766	-2.409	-20.341	-2.483
8	63	64	65	0.000084	-0.000795	-0.000892	-0.000782	-1.801	-16.566	-2.535
9	66	67	68	-0.000073	-0.000668	-0.000436	-0.000827	-1.993	-8.432	-2.680
10	80	81	82	0.000203	-0.000574	0.000168	-0.001519	2.474	3.763	-4.923
11	83	84	85	0.000380	-0.000656	-0.000341	-0.001351	2.706	-5.311	-4.379
12	86	87	88	-0.000145	-0.001010	-0.000109	-0.001766	-1.735	-2.480	-3.724

TABLE E-2. STRAIN GAGE RESULTS, P_{rb}, RUN 2 (SHEET 1 OF 3)

COMPUTER PROGRAM NO. 870-31 DATED: 11-8-1971 R. A. RIDHA RUN DATE: 11/17/71

CONVERSION OF STRAIN ROSETTE READINGS TO STRESSES *IN ORTHOTROPIC MATERIALS*

A-37 LANDING GEAR RUN#2 11-17-1971

**MATERIAL PROPERTIES

EXX= 9299.398 EYY= 17963.098 GXY= 3241.100 MUXY= 0.1559 MUYX= 0.3011

THE C-MATRIX

9757.5	2938.4	0.0
2936.4	18848.0	0.0
0.0	0.0	3241.1

LOAD CALIBRATION FACTOR: 570.000 MICRO IN./KIP. NUMBER OF ROSETTES: 12

TRANSDUCER READING: 22 APPLIED LOAD: 0.039 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	0.000016	0.000015	0.000036	-0.000022	0.262	0.726	-0.071
2	43	44	45	-0.000006	-0.000013	0.000014	-0.000034	-0.017	0.246	-0.110
3	46	47	48	-0.000005	-0.000009	0.000039	-0.000052	0.066	0.720	-0.169
4	50	51	52	0.000011	0.000013	0.000028	-0.000013	0.190	0.560	-0.042
5	53	54	55	-0.000008	-0.000001	0.000010	-0.000004	-0.049	0.165	-0.013
6	56	57	58	-0.000006	-0.000003	0.000005	-0.000005	-0.044	0.077	-0.016
7	60	61	62	0.000041	-0.000009	-0.000013	-0.000046	0.362	-0.125	-0.149
8	63	64	65	-0.000013	-0.000025	-0.000026	-0.000011	-0.203	-0.526	-0.036
9	66	67	68	0.000004	0.000002	-0.000169	0.000169	-0.458	-3.174	0.546
10	80	81	82	0.000035	-0.000002	-0.000005	-0.000034	0.327	0.009	-0.110
11	83	84	85	0.000015	-0.000016	-0.000010	-0.000037	0.117	-0.144	-0.120
12	86	87	88	-0.000012	-0.000048	-0.000040	-0.000044	-0.235	-0.789	-0.143

TABLE E-2. STRAIN GAGE RESULTS, P_{rb}, RUN 2 (SHEET 2 OF 3)

TRANSDUCER READING: 531 APPLIED LOAD: 0.932 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000090	0.000050	0.000502	-0.000312	0.597	9.197	-1.011
2	43	44	45	-0.000100	-0.000067	0.000366	-0.000400	0.100	6.605	-1.296
3	46	47	48	-0.000139	-0.000077	0.000282	-0.000257	-0.528	4.907	-0.963
4	50	51	52	0.000014	0.000044	0.000103	-0.000029	0.439	1.982	-0.094
5	53	54	55	0.000003	0.000026	0.000058	-0.000009	0.200	1.102	-0.029
6	56	57	58	0.000002	-0.000022	-0.000012	-0.000034	-0.016	-0.220	-0.110
7	60	61	62	0.000062	-0.000354	-0.000424	-0.000346	-0.641	-7.809	-1.121
8	63	64	65	0.000020	-0.000332	-0.000357	-0.000327	-0.854	-6.670	-1.060
9	66	67	68	-0.000037	-0.000292	-0.000353	-0.000154	-1.398	-6.762	-0.629
10	80	81	82	0.000093	-0.000235	0.000072	-0.000635	1.119	1.630	-2.058
11	83	84	85	0.000148	-0.000277	-0.000134	-0.000568	1.050	-2.091	-1.841
12	86	87	88	-0.000043	-0.000379	-0.000019	-0.000696	-0.475	-0.484	-2.256

TRANSDUCER READING: 1035 APPLIED LOAD: 1.816 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000217	0.000080	0.000949	-0.000572	0.671	17.249	-1.854
2	43	44	45	-0.000211	-0.000116	0.000708	-0.000729	0.022	12.724	-2.363
3	46	47	48	-0.000280	-0.000152	0.000554	-0.000578	-1.104	9.619	-1.873
4	50	51	52	0.000028	0.000111	0.000228	-0.000034	0.943	4.380	-0.110
5	53	54	55	0.000014	0.000076	0.000145	-0.000007	0.563	2.774	-0.023
6	56	57	58	-0.000005	-0.000034	-0.000018	-0.000045	-0.102	-0.354	-0.146
7	60	61	62	0.000072	-0.000725	-0.000889	-0.000633	-1.910	-16.544	-2.052
8	63	64	65	0.000047	-0.000650	-0.000725	-0.000622	-1.672	-13.527	-2.016
9	66	67	68	-0.000066	-0.000557	-0.000532	-0.000516	-2.207	-10.221	-1.672
10	80	81	82	0.000174	-0.000459	0.000147	-0.001239	2.130	3.282	-4.016
11	83	84	85	0.000308	-0.000536	-0.000268	-0.001112	2.218	-4.146	-3.604
12	86	87	88	-0.000098	-0.000787	-0.000070	-0.001406	-1.162	-1.607	-4.557

TABLE E-2. STRAIN GAGE RESULTS, P_{rb}, RUN 2 (SHEET 3 OF 3)

TRANSDUCER READING: 1680 APPLIED LOAD: 2.947 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000352	0.000110	0.001394	-0.000822	0.661	25.240	-2.604
2	43	44	45	-0.000332	-0.000161	0.001055	-0.001045	-0.139	18.909	-3.387
3	46	47	48	-0.000422	-0.000219	0.000836	-0.000852	-1.661	14.517	-2.761
4	50	51	52	0.000057	0.000166	0.000359	-0.000044	1.611	6.934	-0.143
5	53	54	55	0.000033	0.000127	0.000243	-0.000022	1.036	4.677	-0.071
6	56	57	58	-0.000004	-0.000021	-0.000015	-0.000023	-0.083	-0.294	-0.075
7	60	61	62	0.000092	-0.001073	-0.001347	-0.000891	-3.060	-25.118	-2.868
8	63	64	65	0.000073	-0.000962	-0.001095	-0.000902	-2.505	-20.424	-2.923
9	66	67	68	-0.000093	-0.000800	-0.000686	-0.000821	-2.923	-13.203	-2.661
10	80	81	82	0.000264	-0.000672	0.000228	-0.001836	3.246	5.073	-5.951
11	83	84	85	0.000467	-0.000787	-0.000398	-0.001643	3.387	-6.129	-5.325
12	86	87	88	-0.000161	-0.001205	-0.000116	-0.002133	-1.912	-2.659	-6.913

TRANSDUCER READING: 2057 APPLIED LOAD: 3.609 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000490	0.000140	0.001835	-0.001065	0.611	33.146	-3.452
2	43	44	45	-0.000465	-0.000215	0.001409	-0.001374	-0.397	25.190	-4.453
3	46	47	48	-0.000562	-0.000283	0.001116	-0.001120	-2.204	19.383	-3.630
4	50	51	52	0.000078	0.000258	0.000491	-0.000053	2.204	9.484	-0.172
5	53	54	55	0.000049	0.000176	0.000347	-0.000044	1.493	6.684	-0.143
6	56	57	58	-0.000001	0.000007	-0.000007	0.000017	-0.016	-0.041	0.055
7	60	61	62	0.000103	-0.001430	-0.001816	-0.001147	-4.331	-33.925	-3.718
8	63	64	65	0.000101	-0.001281	-0.001495	-0.001168	-3.407	-27.881	-3.786
9	66	67	68	-0.000123	-0.001064	-0.000862	-0.001143	-3.733	-16.608	-3.705
10	80	81	82	0.000357	-0.000869	0.000301	-0.002436	4.368	6.722	-7.695
11	83	84	85	0.000599	-0.001053	-0.000532	-0.002173	4.282	-8.267	-7.043
12	86	87	88	-0.000194	-0.001584	-0.000134	-0.002840	-2.287	-3.096	-9.205

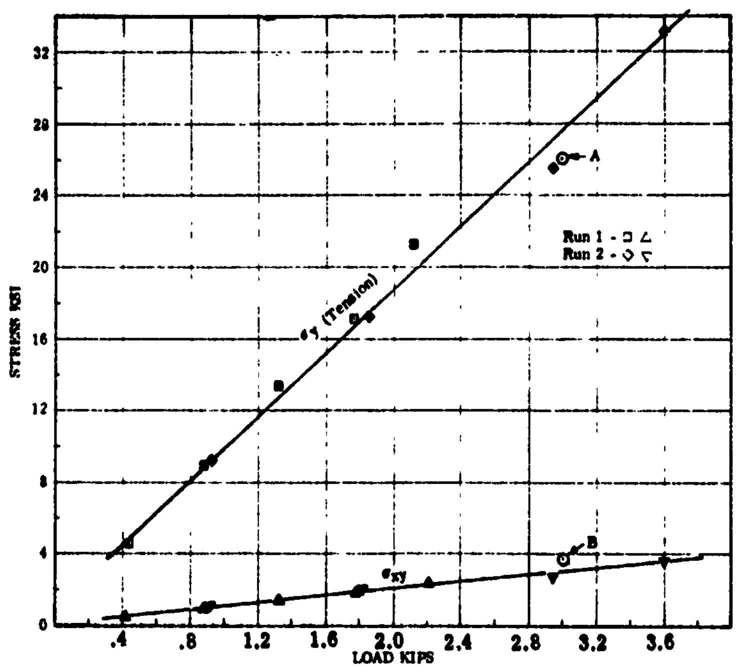


Figure E-4. Strain Results Rossette 1, P_{rb} Load

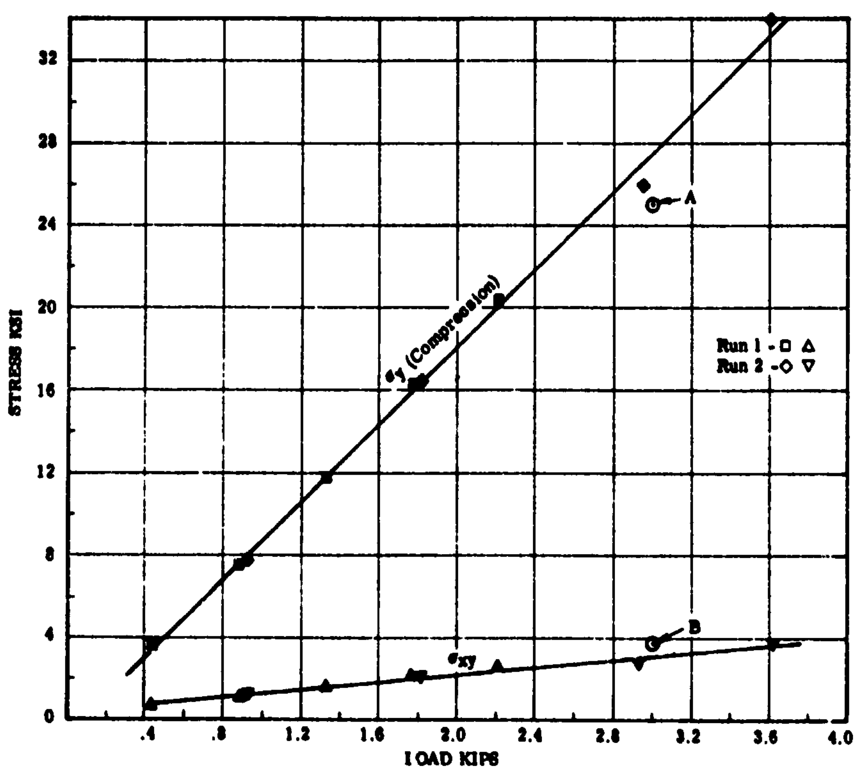


Figure E-5. Strain Results Rossette 7, P_{rb} Load

TABLE E-3. STRAIN GAGE RESULTS, P_{dr} (SHEET 1 OF 4)

COMPUTER PROGRAM NO. 870-31 DATED: 11-8-1971 R. A. RIDHA RUN DATE: 03/07/72

CONVERSION OF STRAIN ROSETTE READINGS TO STRESSES *IN ORTHOTROPIC MATERIALS*

A-37 LANDING GEAR RUN # 3 3/6/72

**MATERIAL PROPERTIES

EXX= 9299.398 EYY= 17963.098 GXY= 3241.100 MUXY= 0.1559 MUYX= 0.3011

THE C-MATRIX

9757.5	2938.4	0.0
2938.4	18848.0	0.0
0.0	0.0	3241.1

LOAD CALIBRATION FACTOR: 361.000 MICRO IN./KIP. NUMBER OF ROSETTES: 12

TRANSDUCER READING: 426 APPLIED LOAD: 1.180 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000091	-0.000072	0.000026	-0.000079	-0.812	0.723	-0.256
2	43	44	45	-0.000115	-0.000065	0.000096	-0.000111	-0.840	1.471	-0.360
3	46	47	48	-0.000102	0.000053	-0.000075	0.000283	-1.216	-1.713	0.917
4	50	51	52	0.000193	0.000080	-0.000028	-0.000005	1.801	0.039	-0.016
5	53	54	55	0.000166	0.000028	-0.000134	0.000024	1.226	-2.038	0.078
6	56	57	58	0.000079	-0.000004	-0.000095	0.000008	0.492	-1.558	0.026
7	60	61	62	-0.000103	-0.000082	-0.000126	0.000065	-1.375	-2.677	0.211
8	63	64	65	-0.000051	-0.000011	-0.000025	0.000054	-0.571	-0.621	0.175
9	66	67	68	-0.000146	-0.000201	-0.000036	-0.000220	-1.530	-1.108	-0.713
10	80	81	82	0.000081	-0.000018	0.000097	-0.000214	1.075	2.066	-0.694
11	83	84	85	0.000006	-0.000079	-0.000084	-0.000080	-0.188	-1.566	-0.259
12	86	87	88	0.000098	0.000097	0.000160	-0.000064	1.426	3.304	-0.207

TABLE E-3. STRAIN GAGE RESULTS, P_{dr} (SHEET 2 OF 4)

TRANSDUCER READING: 870 APPLIED LOAD: 2.410 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000169	-0.000130	0.000087	-0.000178	-1.493	1.143	-0.577
2	43	44	45	-0.000246	-0.000138	0.000185	-0.000215	-1.857	2.764	-0.697
3	46	47	48	-0.000245	0.000104	-0.000162	0.000615	-2.867	-3.773	1.993
4	50	51	52	0.000399	0.000156	-0.000074	-0.000013	3.676	-0.222	-0.042
5	53	54	55	0.000343	0.000060	-0.000276	0.000053	2.536	-4.194	0.172
6	56	57	58	0.000172	0.000007	-0.000176	0.000018	1.161	-2.812	0.058
7	60	61	62	-0.000185	-0.000116	-0.000286	0.000239	-2.646	-5.934	0.775
8	63	64	65	-0.000114	-0.000038	-0.000050	0.000088	-1.259	-1.277	0.285
9	66	67	68	-0.000318	-0.000426	-0.000080	-0.000454	-3.338	-2.442	-1.471
10	80	81	82	0.000193	-0.000025	0.000174	-0.000417	2.394	3.847	-1.352
11	83	84	85	0.000037	-0.000135	-0.000144	-0.000163	-0.062	-2.605	-0.528
12	86	87	88	0.000204	0.000209	0.000331	-0.000117	2.963	6.838	-0.379

TRANSDUCER READING: 1316 APPLIED LOAD: 3.645 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000230	-0.000166	0.000178	-0.000280	-1.721	2.679	-0.908
2	43	44	45	-0.000348	-0.000189	0.000267	-0.000297	-2.611	4.010	-0.963
3	46	47	48	-0.000418	0.000165	-0.000239	0.000987	-4.781	-5.733	3.199
4	50	51	52	0.000564	0.000194	-0.000157	-0.000019	5.042	-1.302	-0.062
5	53	54	55	0.000487	0.000081	-0.000411	0.000086	3.544	-6.316	0.279
6	56	57	58	0.000274	0.000034	-0.000245	0.000039	1.954	-3.813	0.126
7	60	61	62	-0.000211	-0.000097	-0.000406	0.000423	-3.252	-8.272	1.371
8	63	64	65	-0.000161	-0.000086	-0.000091	0.000080	-1.838	-2.188	0.259
9	66	67	68	-0.000522	-0.000670	-0.000112	-0.000706	-5.423	-3.645	-2.288
10	80	81	82	0.000290	-0.000046	0.000216	-0.000598	3.464	4.923	-1.938
11	83	84	85	0.000085	-0.000167	-0.000158	-0.000261	0.365	-2.728	-0.846
12	86	87	88	0.000313	0.000320	0.000515	-0.000188	4.567	10.626	-0.609

TABLE E-3. STRAIN GAGE RESULTS, P_{dr} (SHEET 3 OF 4)

TRANSDUCER READING: 1771 APPLIED LOAD: 4.906 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000274	-0.000184	0.000297	-0.000391	-1.801	4.793	-1.267
2	43	44	45	-0.000469	-0.000256	0.000334	-0.000377	-3.595	4.917	-1.222
3	46	47	48	-0.000622	0.000232	-0.000288	0.001374	-6.915	-7.256	4.453
4	50	51	52	0.000723	0.000219	-0.000253	-0.000032	6.311	-2.644	-0.104
5	53	54	55	0.000630	0.000102	-0.000545	0.000119	4.546	-8.421	0.386
6	56	57	58	0.000387	0.000061	-0.000312	0.000047	2.859	-4.743	0.152
7	60	61	62	-0.000217	-0.000064	-0.000518	0.000607	-3.639	-10.401	1.967
8	63	64	65	-0.000234	-0.000156	-0.000154	0.000076	-2.736	-3.590	0.246
9	66	67	68	-0.000755	-0.000917	-0.000134	-0.000945	-7.761	-4.744	-3.063
10	80	81	82	0.000384	-0.000081	0.000250	-0.000796	4.481	5.840	-2.580
11	83	84	85	0.000118	-0.000214	-0.000179	-0.000367	0.625	-3.027	-1.189
12	86	87	88	0.000419	0.000428	0.000700	-0.000263	6.145	14.425	-0.852

TRANSDUCER READING: 2224 APPLIED LOAD: 6.161 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000306	-0.000184	0.000427	-0.000489	-1.731	7.149	-1.585
2	43	44	45	-0.000600	-0.000326	0.000405	-0.000457	-4.664	5.870	-1.481
3	46	47	48	-0.000866	0.000302	-0.000311	0.001781	-9.364	-8.406	5.772
4	50	51	52	0.000889	0.000238	-0.000367	-0.000046	7.596	-4.305	-0.149
5	53	54	55	0.000787	0.000125	-0.000682	0.000145	5.675	-10.542	0.470
6	56	57	58	0.000517	0.000091	-0.000382	0.000047	3.922	-5.681	0.152
7	60	61	62	-0.000203	-0.000012	-0.000620	0.000799	-3.803	-12.282	2.590
8	63	64	65	-0.000304	-0.000214	-0.000197	0.000073	-3.545	-4.606	0.237
9	66	67	68	-0.001015	-0.001154	-0.000132	-0.001161	-10.292	-5.470	-3.763
10	80	81	82	0.000484	-0.000111	0.000289	-0.000995	5.572	6.869	-3.225
11	83	84	85	0.000140	-0.000267	-0.000198	-0.000476	0.784	-3.321	-1.543
12	86	87	88	0.000525	0.000547	0.000902	-0.000333	7.773	18.544	-1.079

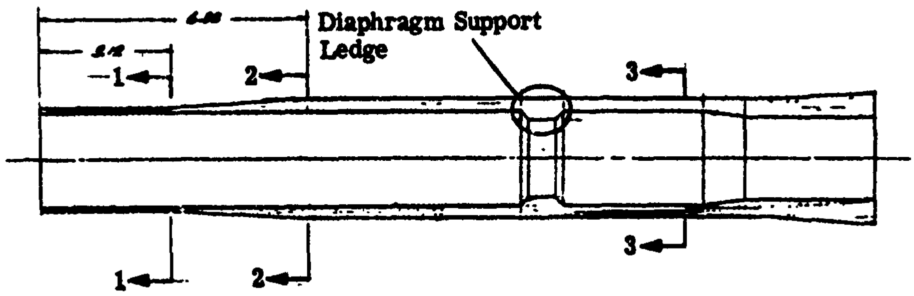
TABLE E-3. STRAIN GAGE RESULTS, P_{dr} (SHEET 4 OF 4)

TRANSDUCER READING: 6 APPLIED LOAD: 0.017 KIPS

ROSETTE	CHANNEL #1	#2	#3	EPX=EP1	EP2	EPY=EP3	EPXY	SIG X	SIG Y	SIG XY
1	40	41	42	-0.000004	0.000004	0.000016	-0.000004	0.008	0.290	-0.013
2	43	44	45	-0.000013	0.000004	0.000016	0.000005	-0.080	0.263	0.016
3	46	47	48	-0.000009	-0.000009	-0.000021	0.000012	-0.150	-0.422	0.039
4	50	51	52	0.000012	0.000008	-0.000006	0.000010	0.099	-0.078	0.032
5	53	54	55	0.000019	0.000012	-0.000005	0.000010	0.171	-0.038	0.032
6	56	57	58	0.000017	0.000005	-0.000009	0.000002	0.139	-0.120	0.006
7	60	61	62	-0.000007	-0.000008	0.000003	-0.000017	-0.045	0.130	-0.055
8	63	64	65	-0.000005	-0.000010	0.0	-0.000015	-0.049	-0.015	-0.049
9	66	67	68	-0.000010	-0.000017	-0.000010	-0.000014	-0.127	-0.218	-0.045
10	80	81	82	0.000007	-0.000009	-0.000003	-0.000022	0.059	-0.036	-0.071
11	83	84	85	0.000021	0.000004	-0.000018	0.000005	0.152	-0.278	0.016
12	86	87	88	0.000010	0.000002	0.000006	-0.000012	0.115	0.142	-0.039

Appendix F

STRESS ANALYSIS OF BORON-EPOXY PISTON



The cylinder sections refer to those labelled above. The internal cross section loads were derived from the external loads shown in Table 4-1.

ULTIMATE LOADS

Cylinder Sections	Load Condition Table 4-1	Bending Moment in.-lbs.	Axial Compression lbs.	Torsion, in.-lbs.	Shear lbs.
1	3B	37,000	0	0	13,300
2	3B	80,000	0	0	13,300
3	6A	176,000	11,000	0	11,600

SECTION PROPERTIES

Section	OD in.	ID in.	t in.	A $in.^2$	I $in.^4$	I/c $in.^3$
1	2.37	2.17	0.10	0.71	0.46	0.39
2,3	2.67	2.17	0.25	1.90	1.41	1.05

Section 1-1

Shear $$f_s = \frac{2V}{A} = \frac{2 \times 13{,}300}{0.71} = 37{,}000 \text{ psi}$$

Plots as point A on Figure F-1

$$MS = \frac{45}{37} - 1 = 0.22$$

Bending $$f_b = \frac{M}{I/c} = \frac{37{,}000}{0.39} = 95{,}000 \text{ psi}$$

Plots as point B on Figure F-1

$$MS = \frac{100}{95} - 1 = 0.05$$

Section 2-2

Bending $$f_b = \frac{Mc}{I} = \frac{80{,}000}{1.05} = 76{,}000 \text{ psi}$$

Plots as point C on Figure F-1

$$MS = \frac{100}{76} - 1 = 0.32$$

Section 3-3

Bending $$f_b = \frac{176{,}000}{1.05} = 168{,}000 \text{ psi}$$

$$f_c = \frac{P}{A} = \frac{11{,}000}{1.90} = 6000 \text{ psi}$$

$$f_x = 168{,}000 - 6000 = 162{,}000 \text{ psi}$$

Plots as point A on Figure F-2

$$MS = \frac{168}{162} - 1 = 0.04$$

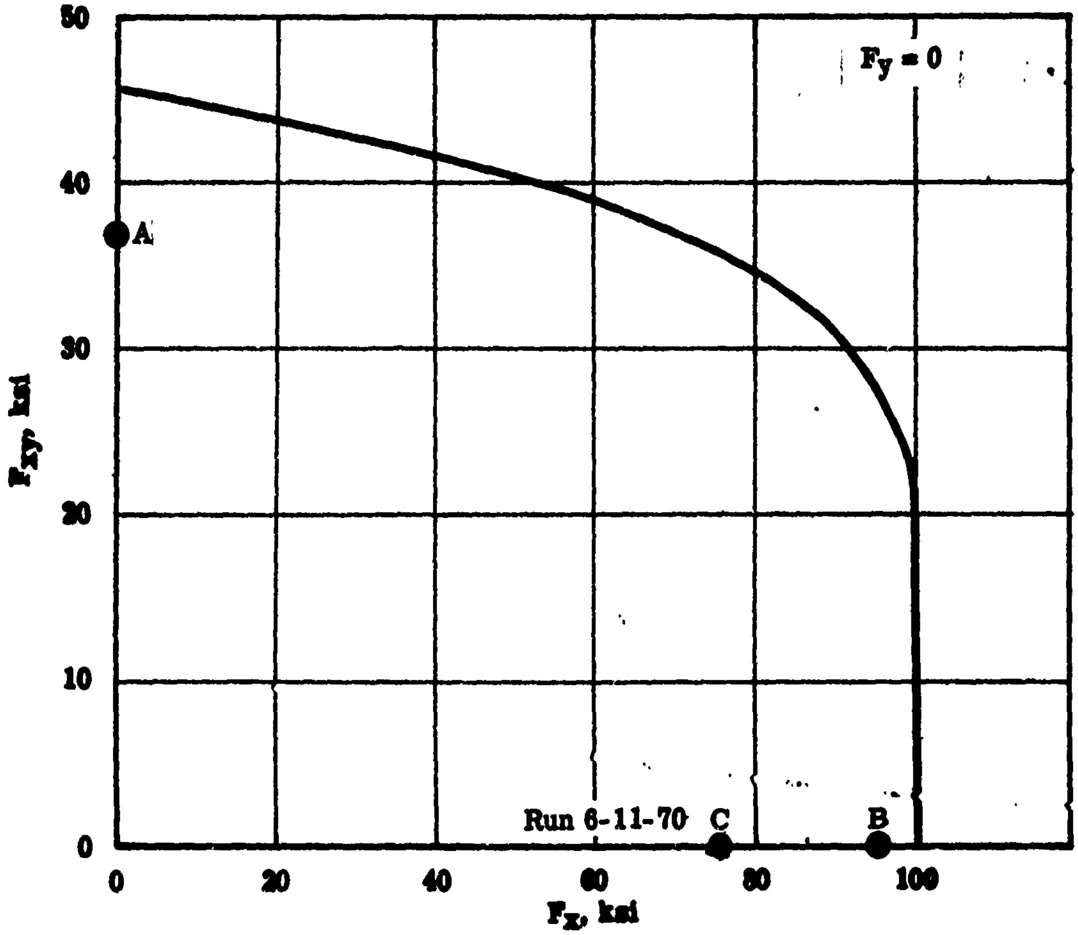


Figure F-1. Ultimate Strength Envelope Boron-Epoxy
($0_2°$, ±45°, 90°) Laminate

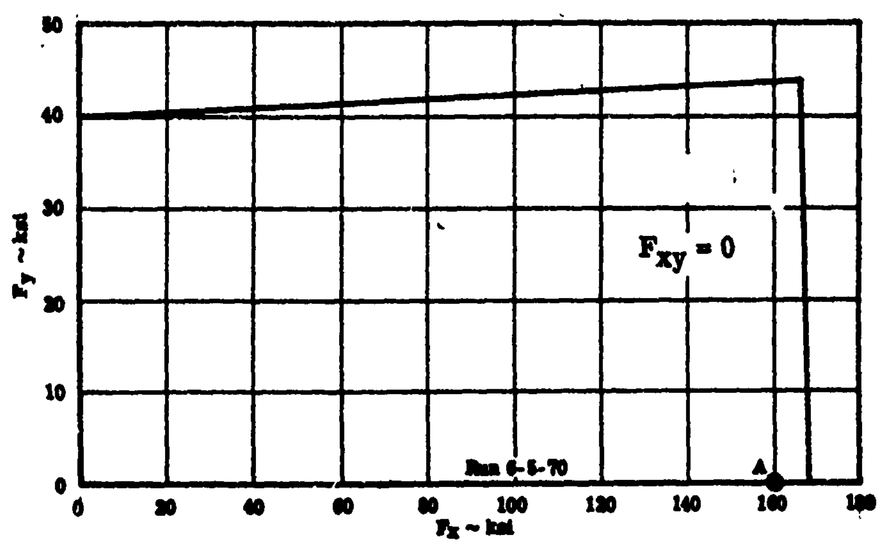


Figure F-2. Ultimate Strength Envelope Boron-Epoxy
($0_4°$, 90°) Laminate

Analysis of Diaphragm Support Ledge, Boron-Epoxy Piston

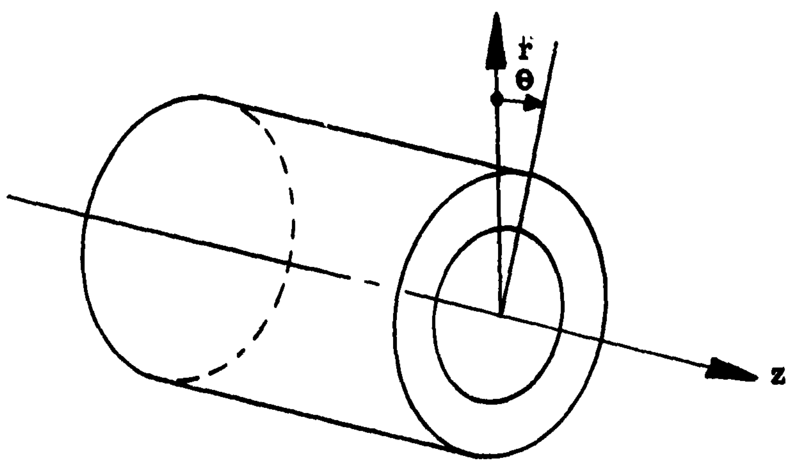
Refer to Figure 5-92 for an illustration of this detail. The purpose of this ledge is to contain the metering pin support diaphragm, Figure 6-6 and Figure 6-7. This ledge creates a sudden change in radial stiffness of the cylinder wall at this location. This region is subjected to the high pressure of the dynamic pressure chamber during shock absorber stroke. There was concern that the outward radial deflection of the basic tube wall would separate the tube wall from the ledge along the weak interlaminar surface between the two. The following finite element stress analysis of this condition was performed to check the stress levels along the interlaminar surface.

Method - The structure was idealized as an assembly of triangular ring elements as shown in Figure F-3. In a cross section, the corners of the triangles are referred to as joints. Using energy principles, the stiffness of each element is calculated as function of its geometry and material properties. The element-stiffness matrices are assembled into a large stiffness matrix referring to the whole structure.

Given the loads applied at various joints, the displacements of all the joints are calculated. Based on the values of the displacements of its three corner joints, the strains in each element are calculated. The stresses are then calculated from the strains.

The theory was initially developed for axisymmetric bodies made of homogeneous isotropic materials, Reference 20. The concept was extended by Bendix to nonhomogeneous structures. Allowing for change of material properties among the elements, the element-stiffness matrices are calculated from their corresponding stess-strain matrices. The latter matrices are modified to incorporate orthotropic properties.

Material properties, loads and stresses are given with respect to the orientation defined below.



Material Properties

The basic tube wall material ($0°_4$, 90°) was assigned the following elastic properties.

$E_{rr} = 3.1 \times 10^6$ psi

$E_{zz} = 25 \times 10^6$ psi

$E_{\theta\theta} = 8.5 \times 10^6$ psi

$G_{rz} = G_{r\theta} = G_{z\theta} = 0.8 \times 10^6$

$\nu_{rz} = 0.016 \qquad \nu_{zr} = 0.13$

$\nu_{r\theta} = 0.047 \qquad \nu_{\theta r} = 0.13$

$\nu_{z\theta} = 0.06 \qquad \nu_{\theta z} = 0.02$

Elements belonging to the ledge (0°, 90°) were assigned the following properties:

$E_{rr} = 3.1 \times 10^6$ psi

$E_{zz} = E_{\theta\theta} = 16.7 \times 10^6$ psi

$G_{rz} = G_{r\theta} = G_{z\theta} = 0.8 \times 10^6$ psi

$\nu_{rz} = \nu_{r\theta} = 0.06 \qquad \nu_{zr} = \nu_{\theta r} = 0.086$

$\nu_{z\theta} = 0.03 \qquad \nu_{\theta z} = 0.03$

Loading - Based on a 1000 psi pressure, the concentrated radial pressures at joints 1, 4, 7, - - -, 22 above the ledge were calculated. The resultant press force on the diaphragm was resolved into radial and longitudinal components and applied at the seat joints 25, 28, and 33, Figure F-3. The joint loads shown are total circumferential load in kips.

Support Conditions

In order to represent the original, longer tube, the six-inch long tube being analyzed has the longitudinal displacement suppressed along the right end. Preventing these displacements (at joints 73, 74, 75) maintains the vertical position of the edge. To prevent rigid body movements, one of the joints at the support end (joint 73) is constrained against displacement in the radial and circumferential directions.

Stress Results - The stress results are shown plotted with respect to the distance along the interlaminar surface, Figure F-4, for a fluid pressure of 1000 psi. Note that radial stress is compressive which indicates a tendency for the ledge and the basic cylinder to be forced together. The highest stress along the interface is a shear stress τ_{rz} of approximately 1000 psi.

The highest pressure which will be experienced by the dynamic pressure chamber will be 4600 psi ultimate due to the 3G taxi condition. This would indicate a maximum shear stress along the interface of

$$4.6 \times 1000 = 4600 \text{ psi}$$

which is well within the allowable interlaminar strength for this material.

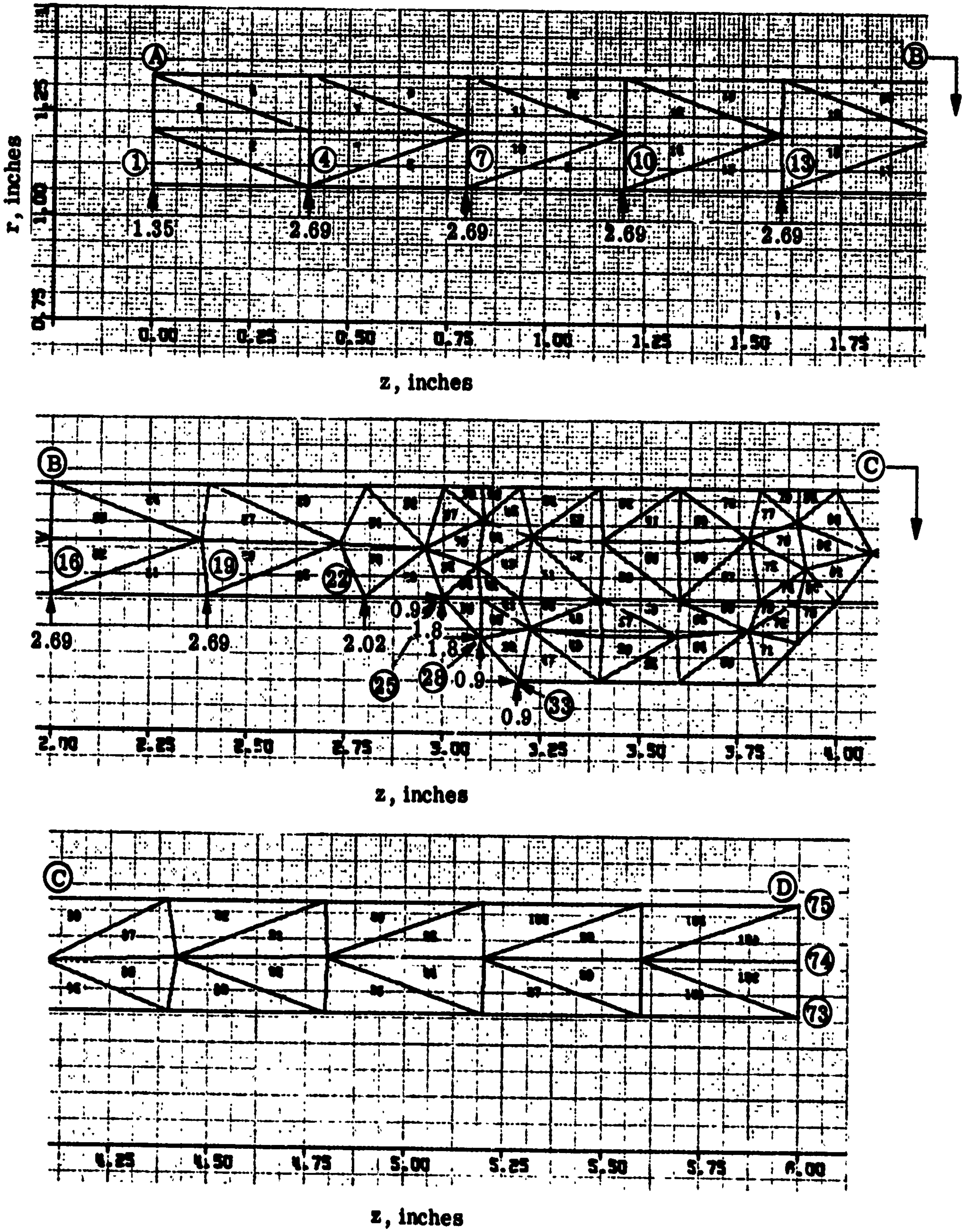


Figure F-3. Finite Element Grid, Loads in Kips

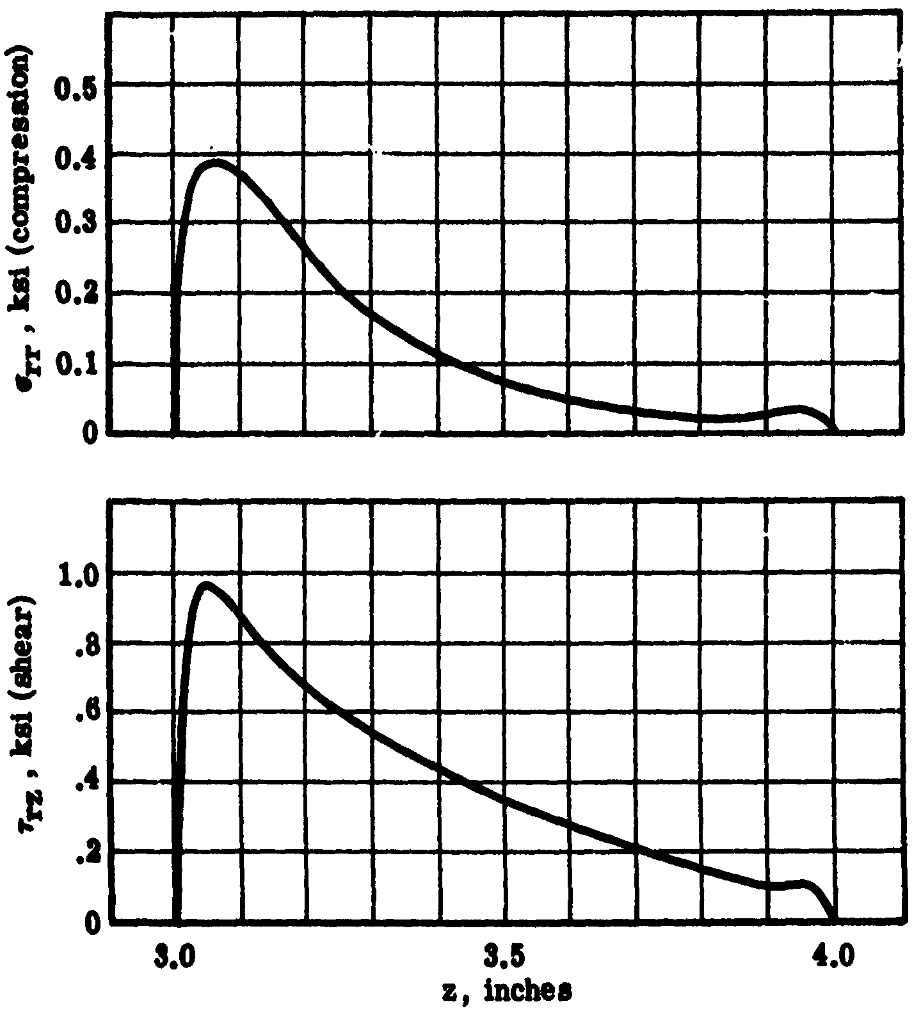


Figure F-4. Stress along Interlaminar Surface for 1000 psi Pressure

Appendix G

STRAIN GAGE ANALYSIS OF SIDE BRACE

1. Strain Measurements

Testing of the side brace is described in Paragraph 7.2.2.2.

Strain gage locations are shown in Figure G-1. Three groups of strain gages were applied.

Group 1 - Axially oriented single gages were applied to the boron composite flanges - gage numbers 17 to 22, inclusive. The results from these gages are plotted in Figures G-2 and G-3.

Group 2 - Axially oriented single gages were applied to the aluminum over center lock finger - gage numbers 23 to 26, inclusive. The results are plotted in Figure G-4.

Group 3 - Gages were also applied to the metal end fittings. However, the Stage 1 failure of the brace (Paragraph 7.2.2.2) rendered these gages inoperative before suitable measurements could be made.

2. Numerical Analysis of the Results

Group 1 Gages

The basic load carrying cross section consists of three load carrying elements

1 - axial filaments
2 - transverse filaments
3 - honeycomb

The loads carried by these individual elements are P_1, P_2 and P_3, respectively. The total load carried is

$$P = P_1 + P_2 + P_3$$

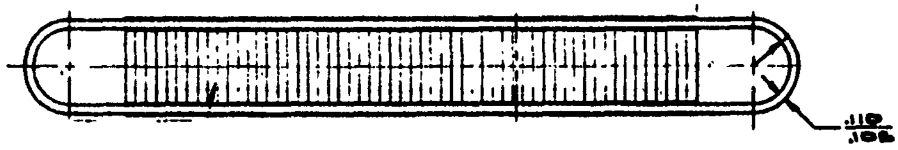
Assuming the strain e is constant through the cross section

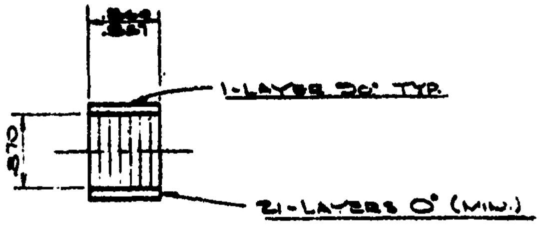
$$P = E_1 e A_1 + E_2 e A_2 + E_3 e A_3$$

or

$$e = \frac{P}{E_1 A_1 + E_2 A_2 + E_3 A_3}$$

(a) Lower Member





Axial Filaments -

$$A_1 = 2(.11)(.860) = .189 \text{ in.}^2$$

As indicated in Paragraph 8.2.3.2, 24 layers of filaments were applied rather than 21. Therefore

$$E_1 = \frac{24}{21} \times 30.3 \times 10^6 = 34.6 \times 10^6 \quad \text{(Table 4-3)}$$

Transverse Filaments -

$$A_2 = 4(.0053)(.86) = .018 \text{ in.}^2$$

$$E_2 = 3.1 \times 10^6 \qquad \text{(Table 4-3)}$$

Honeycomb -

Assume outer one fourth only of honeycomb is effective in load carrying - stabilized by bond to filament band.

$$A_3 = 1/4(.87)(.86)\,2 = .374 \text{ in.}^2$$

Honeycomb density = 23.1 lb/ft^3 = .0134 lb/in.^{3}
Aluminum density = .101 lb/in.^{3}

$$E_3 = \frac{.0134}{.101} \times 10.5 \times 10^6 = 1.4 \times 10^6$$

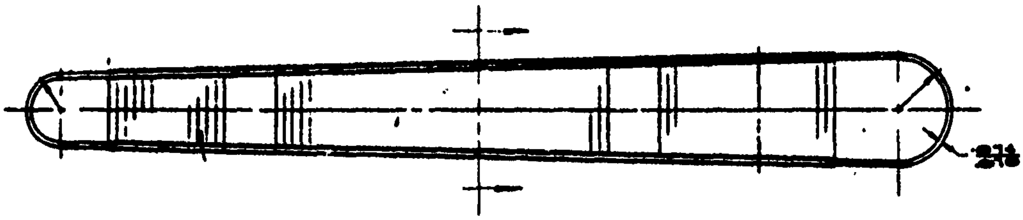
Strain per 1000 lb. of load -

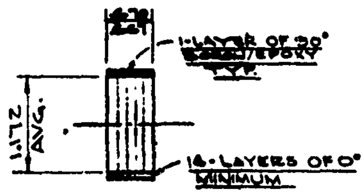
$$e = \frac{1000}{(34.6 \times .189 + 3.1 \times .018 + 1.4 \times .374)10^6}$$

$$e = \frac{1000}{(6.54 + .056 + .524)10^6} = 140\ \mu\text{in./kip}$$

This compares with measured strains of 128 and 138 μin./kip, Figure G-2.

(b) Upper Member





Axial Filaments -

$$A_1 = 4(.072)(.67) = .193 \text{ in.}^2$$

As indicated in Paragraph 8.2.3.2, 17 layers of filaments were applied rather than 14. Therefore

$$E_1 = \frac{17}{14} \text{X } 30.3 \text{ X } 10^6 = 36.8 \times 10^6 \qquad \text{(Table 4-3)}$$

Transverse Filaments -

$$A_2 = 8(.0053)(.67) = .0284 \text{ in.}^2$$

$$E_2 = 3.1 \times 10^6 \text{ psi} \qquad \text{(Table 4-3)}$$

Honeycomb -

$$A_3 = 2 \times 2 \times 1/4\ (1.172)(.67) = 0.785 \text{ in.}^2$$

$$E_3 = 1.4 \times 10^6 \text{ psi} \qquad \text{(See lower member)}$$

Strain -

$$e = \frac{1000}{(36.8 \times .193 + 3.1 \times 0.0284 + 1.4 \times 0.758)10^6}$$

$$e = \frac{1000}{(7.1 + .09 + 1.06)10^6} = 121\ \mu\text{in/kip}$$

This compares with measured strains of 123 and 124 μ in/kip, Figure G-3.

Group 2 Gages

Referring to Figure G-4, the strain rate may be determined by the expression

$$e = \frac{\Delta e}{\Delta p}$$

With no lateral support

$$e = \frac{550-100}{6} = 75 \ \mu \text{in/kip}$$

With lateral support

$$e = \frac{650}{8} = 81 \ \mu \text{in/kip}$$

As an approximation

$$e \simeq 80 \ \mu \text{in/kip}$$

Using $E = 10.5 \times 10^6$ psi for aluminum

$$f \approx 10.5 \times 80 = 850 \text{ psi/kip}$$

The strain follows a non-linear relation to load; however assuming linear variation as an approximation, the stress at ultimate load, 30 kips, would be

$$f_{ult} = 30 \times 850 = 25400 \text{ psi}$$

For this grade of aluminum

$$F_{ty} \approx 65000 \text{ psi}$$

Margin available for non-linear deflection,

$$\approx \frac{65000}{25400} = 2.5$$

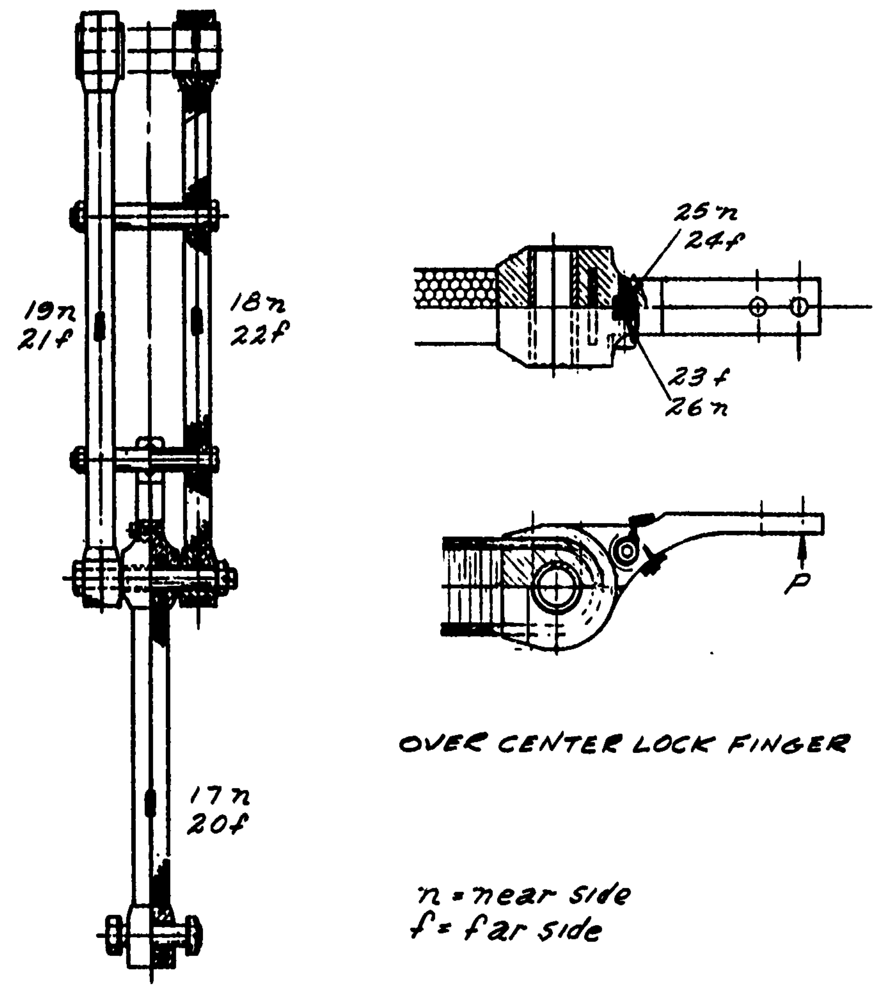
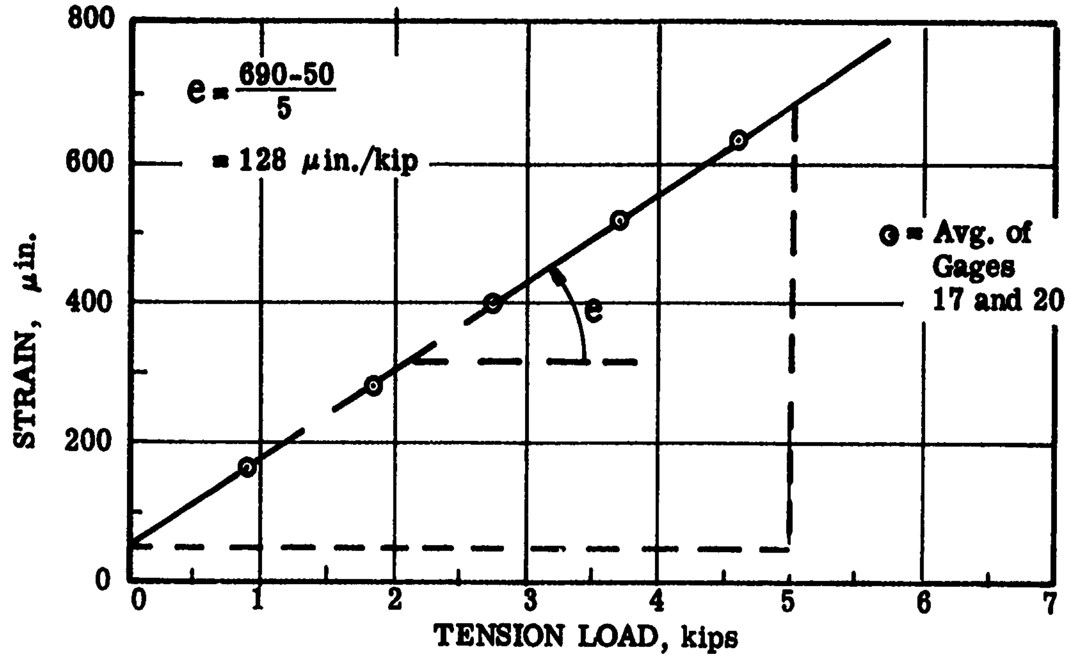


Figure G-1. Side Brace Strain Gage Locations



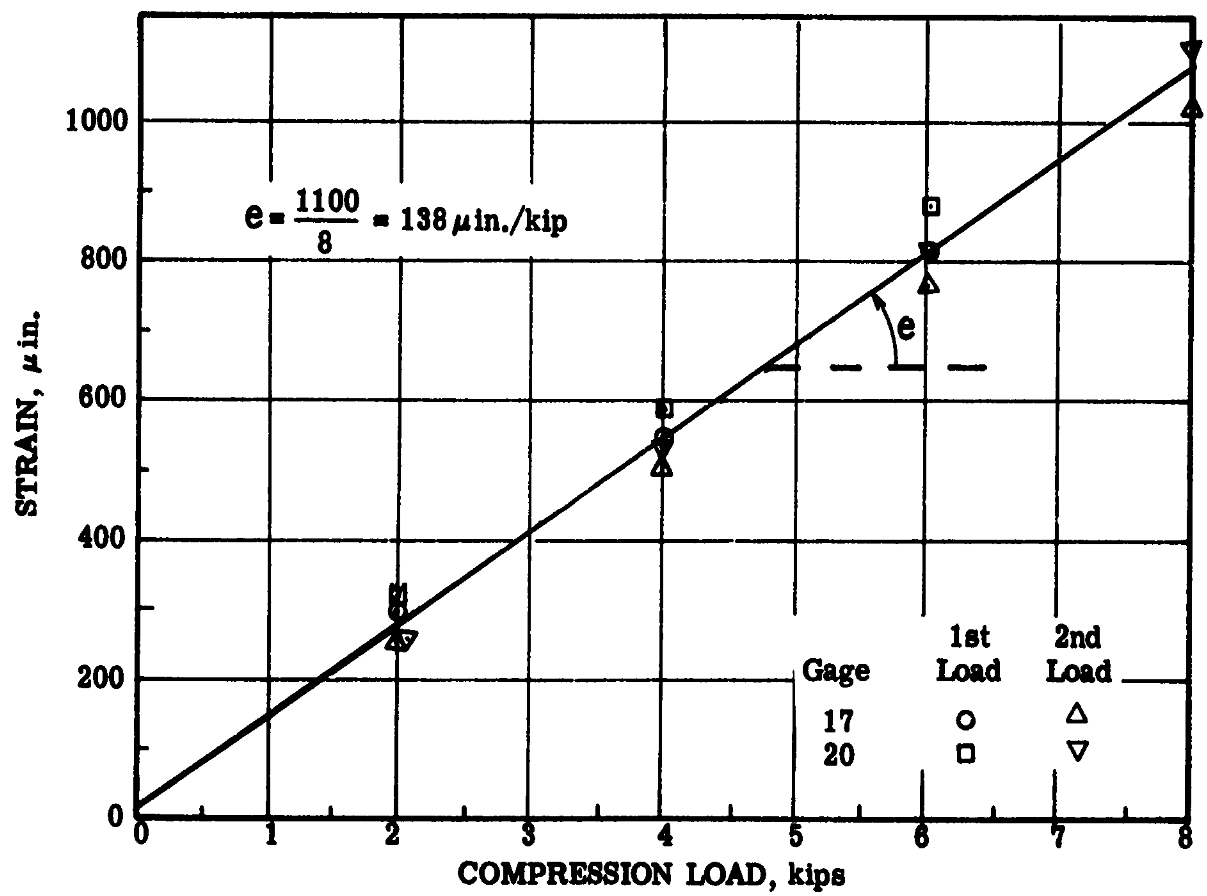
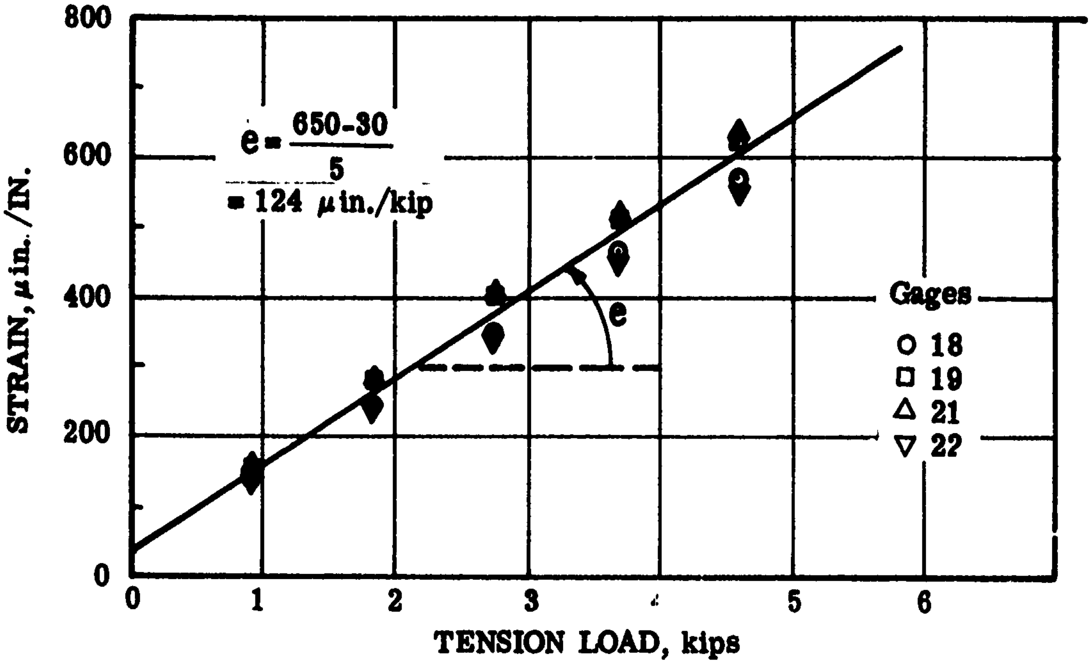


Figure G-2. Strains, Side Brace Lower Member



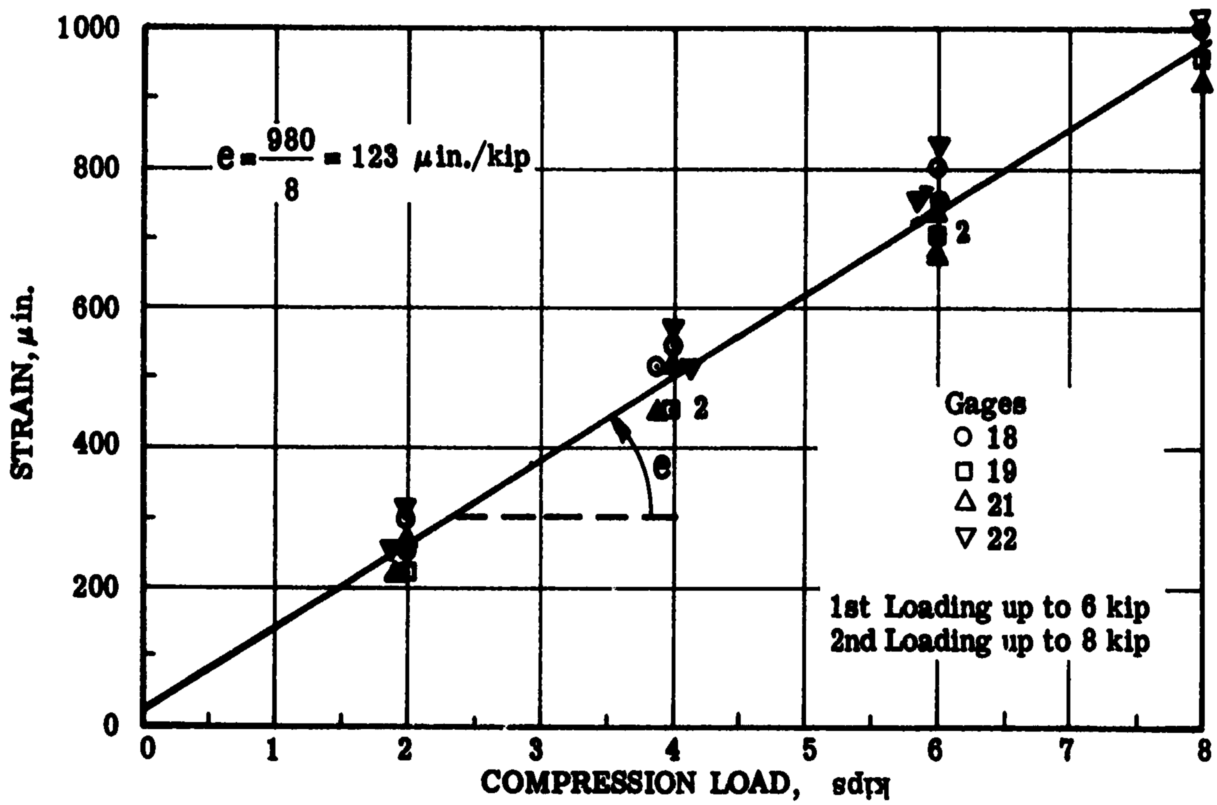


Figure G-3. Strains, Side Brace Upper Member

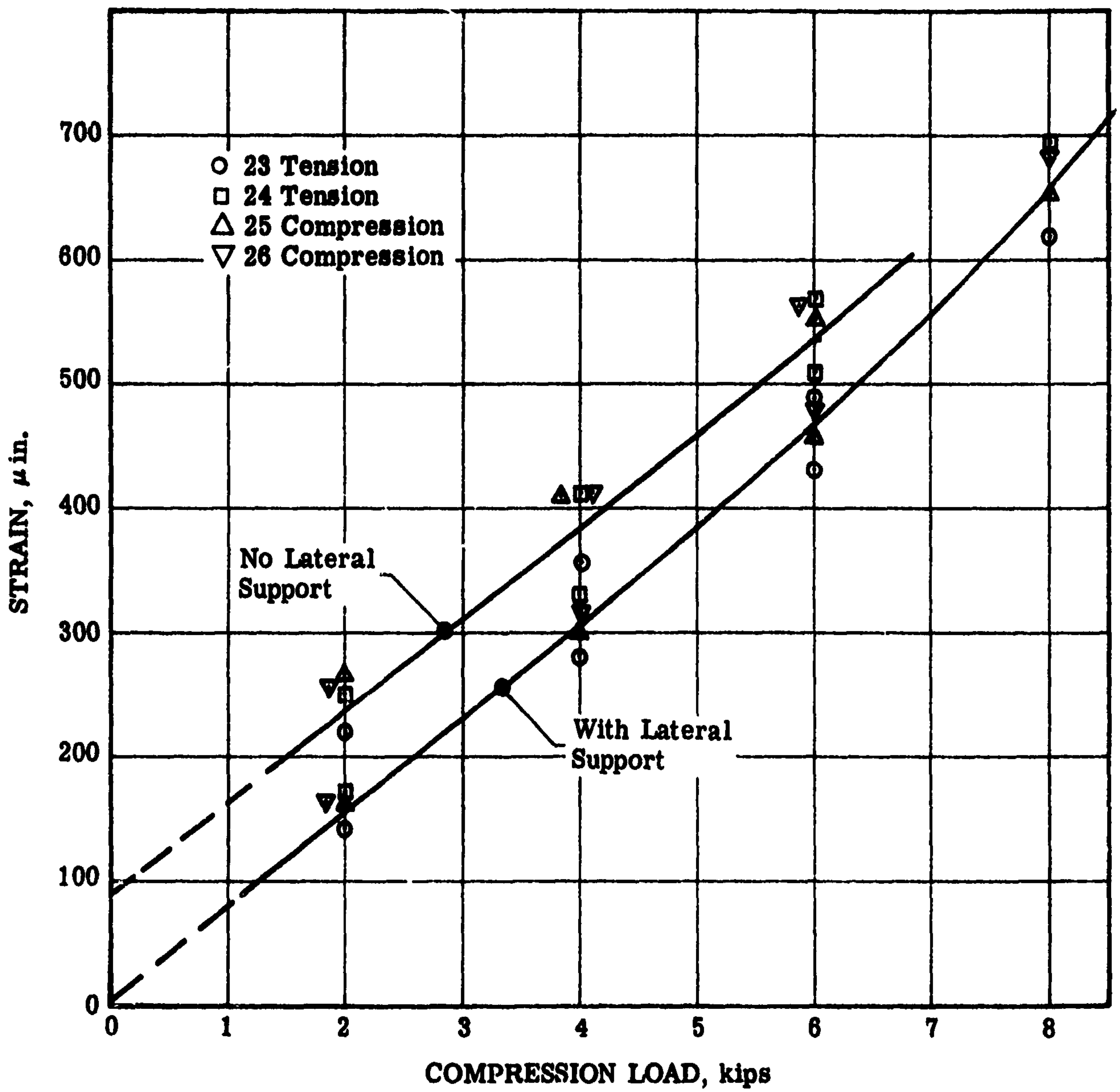


Figure G-4. Strains, Overcenter Lock Finger

Landing Gear Parts List - Aircraft Version

THE BENDIX CORPORATION
ENERGY CONTROLS DIVISION
SOUTH BEND, INDIANA 46620, U.S.A.

PARTS LIST

CHECKED BY ________
COMPILED BY R. E. Mikel

PL VXR-31211
DATE March 15, 1971

ITEM	NOTE	PART NUMBER	CUSTOMER PART NO.	NO. REQD	NAME	CHANGE SERIAL NO.	NO. REQD LH	NO. REQD RH
1		VXR-31211			Shock Strut Assy. - Pneud. - Main Wheel - L.H.		One	
2								
3								
4		VXD-31129			Cylinder and Orifice Tube Assy. L.H.		One	
5								
6		VXD-31128			Cylinder and Trunnion Assy.		One	
7								
8		VXD-31091			Cylinder - finished		1	
9		VXD-31090			Cylinder - Semi-finished		1	
10		VXD-31089			Cylinder - Tube Blank		1	
11		VXD-31094			Fitting - Center		1	
12		VXD-31095			Ring - Threaded Retainer		1	
13		VXC-31096			Ring - Ferrule		1	
14		VXC-31097			Sleeve - Spacer		1	
15		VXC-31093			Fitting - Lower		1	
16		VXD-31126			Trunnion		1	
17		VXC-31127			Ring - Cylinder Retainer		1	
18								
19								
20		VXC-31149			Tube Assy. - Orifice Support		One	
21		VXC-31146			Tube - Orifice Support		1	
22		VXC-31145			Plate - Orifice Tube Support		1	
23		VXC-31148			Plate - Orifice Retainer		1	
24		167398			Orifice		1	
25		167399			Pin-Lock		8	
26		1191-8CNx5 162515			Insert - Threaded (heli-coil, special)		1	
27		167393			Pin		1	
28		MS-20995-F47 67449			Lockwire (9" Long)		2	
29								
30		VXC-31151			Ring - Piston		1	
31		AN-6230-12			Seal - "O" Ring		1	
32		MS-28774-234			Ring - Back up		1	
33								

NOTES Revised 5/26/71

NAME Shock Strut Assembly pneudraulic Main Landing Gear L.H. - Advanced Composite Structure

CODE IDENT NO. 06848

ENGRG DEPT Analytical Mechanics
REL DATE
MODEL A-37B
SHEET NO. 1 NO. OF SHEETS 6
SERIAL NO.
PL VXR-31211

Figure H-1. Parts List Aircraft Version (Sheet 1 of 6)

THE BENDIX CORPORATION

ENERGY CONTROLS DIVISION

SOUTH BEND, INDIANA 46620, U.S.A.

PARTS LIST

CHECKED BY ________

COMPILED BY R. E. Mikel

PL VXR-31211

DATE March 15, 1971

ITEM	NOTE	PART NUMBER	CUSTOMER PART NO.	NO. REQD	NAME	CHANGE SERIAL NO.	NO. REQD LH	NO. REQD RH
1		AN4-20A 195-S-76			Bolt		2	
2		MS20364-428A 908982-K1			Nut		2	
3		AN960-416 911245			Washer		2	
4		167361			Pin - Trunnion (AFT)		1	
5		167362			Pin - Trunnion (FWD)		1	
6		167364			Stud - Door Latch		1	
7		AN960-516 911247			Washer		1	
8		MS20364-524A 908983K1			Nut		1	
9		163511			Pin - Roll (ESNA 52-028-125-0750)		1	
10								
11		NA5464-P5A19 167888			Bolt		2	
12		AN960-516 911247			Washer		4	
13		MS20364-524A 908983K1			Nut		2	
14								
15		2572948			Arm Assy-Actuator		One	
16		2572947			Arm - Actuator		1	
17		173425			Arm - Actuator (forg.)		1	
18		NAS516-1 161256			Lubricator		1	
19		NAS182-5 168086			Bearing - Self Aligning		1	
20								
21								
22								
23		VXD-31130			Piston Assy. L. H.		One	
24								
25		VXD-31131			Piston and Axle Assy. L. H.		One	
26								
27		VXD-31099			Piston - Finished		1	
28		VXD-31098			Tube - Piston Blank		1	
29		VXC-31137			Sleeve - Valve Guide		1	
30		VXD-31113			Axle		1	
31		VXC-31165			Ring Set - Wheel Stop		2	
32		VXC-31132			Retainer Assy. - Piston		One	
33		VXC-31133			Retainer - Threaded		1	

NOTES Revised 5/26/71

NAME Shock Strut Assembly - Pneudraulic Main Landing Gear L. H. - Advanced Composite Structure

ENGRG DEPT Analytical Mech

REL DATE

MODEL A-37B

SHEET NO. 2

NO. OF SHEETS 6

SERIAL NO.

CODE IDENT NO. 06848

PL VXR-31211

Figure H-1. Parts List Aircraft Version (Sheet 2 of 6)

THE BENDIX CORPORATION
ENERGY CONTROLS DIVISION
SOUTH BEND, INDIANA 46620, U.S.A.

PARTS LIST

CHECKED BY ______
COMPILED BY R. E. Mikel

PL VXR-31211
DATE March 15, 1971

ITEM	NOTE	PART NUMBER	CUSTOMER PART NO.	NO. REQD	NAME	CHANGE SERIAL NO.	NO. REQD LH	NO. REQD RH
1								
2		VXC-31134			Point - Jack		1	
3		VXC-31143			Plate - Packing Retainer		1	
4		VXC-31144			Scraper - Piston Rod		1	
5		VXC-31135			Bearing - Lower		1	
6		AN 6230-12 300-S-12			Seal 'O' Ring		1	
7		MS28774-234			Ring - Back-up		1	
8		733H4FT-160A 87449-1001			Seal - Piston (T Ring)		1	
9		733H4FT-2T			Ring - Back-up		2	
10		VXC-31203			Tube Spacer		1	
11		VXC-31138			Valve - Snubber		1	
12		VXC-31139			Bearing - Upper		1	
13		VXC-31140			Sleeve - Bearing Lock		1	
14								
15								
16		VXC-31141			Diaphragm and Nut Assy.		One	
17		VXC-31142			Plate - Diaphragm		1	
18		52A1-080 157564			Nut - Self Locking		1	
19		156369			Screw-Dr. Hd. Fillister		2	
20		MS20995-F32 68829			Wire - Lock (4" Long)		1	
21		AN6230-3 300-S-3			Seal - 'O' Ring		1	
22		MS28774-226			Ring - Backup (cut to match at Assy.)		1	
23		169607			Pin Metering		1	
24		AN6227-11 250-S-11			Seal - "O" Ring		1	
25								
26								
27		MS21025-28 952227			Nut - Axle		1	
28		AN7503-28 110-S-29			Washer-Wheel Brg. Ret.		1	
29		MS24665-446 161099			Pin - Cotter		1	
30		2574080			Retainer-Brg. Outer		1	
31								
32								
33								

NOTES Revised 5/26/71

NAME Shock Strut Assembly - Pneudraulic Main Landing Gear L. H. - Advanced Composite Structure

CODE IDENT NO. 06848

ENGRG DEPT Analytical Mech.
REL DATE MODEL A-37B
SHEET NO. 3 NO. OF SHEETS 6
SERIAL NO.
PL VXR-31211

Figure H-1. Parts List Aircraft Version (Sheet 3 of 6)

THE BENDIX CORPORATION
ENERGY CONTROLS DIVISION
SOUTH BEND, INDIANA 46620, U.S.A.

PARTS LIST

CHECKED BY
COMPILED BY R. E. Mikel

PL VXR-31211
DATE March 15, 1971

ITEM	NOTE	PART NUMBER		CUSTOMER PART NO.	NO. REQD	NAME	CHANGE SERIAL NO.	NO. REQD LH	NO. REQD RH
1			VXD-31214			Torque Arm Assembly		One	
2			167857			Torque Arm Assy. Upper		One	
3			167858			Arm - Torque - Upper		1	
4			167405			Arm - Torque (Forging)		(1)	
5			167408			Bushing - Root		2	
6			167407			Bushing - Knee		1	
7									
8			2575385			Torque Arm Assy. - Lower		One	
9			2575383			Arm - Torque - Lower		1	
10			167405			Arm - Torque (Forging)		(1)	
11			167408			Bushing - Root		2	
12			167407			Bushing - Knee		1	
13			167409			Washer (Special)		1	
14			174986			Bolt - (Special)		1	
15		AN-310-6	900849K1			Nut - Castle		1	
16		AN-392-19	160740			Pin - Flat Head		1	
17		AN-380-2-1	901207K1			Pin - Cotter		1	
18		AN-122584	174987			Washer - Flat		2	
19			2576838			Pin Torque Arm - Root		2	
20		MS20364-1032A	908981-K1			Nut		2	
21		AN960-10	911243			Washer		2	
22									
23		AN23-22A	165515			Bolt - Clevis		2	
24									
25		MS15001-1	53885			Lubricator		6	
26									
27									
28									
29									
30									
31									
32									
33									

NOTES Revised 5/26/71

NAME Shock Strut Assembly - Pneudraulic Main Landing Gear L.H. - Advanced Composite Structure.

CODE IDENT NO. 06848

ENGRG DEPT Analytical Mechanics
REL DATE
MODEL
SHEET NO. 4
NO. OF SHEETS 6
SERIAL NO.
PL VXR-31211

Figure H-1. Parts List Aircraft Version (Sheet 4 of 6)

THE BENDIX CORPORATION
ENERGY CONTROLS DIVISION
SOUTH BEND, INDIANA 46620, U.S.A.

PARTS LIST

CHECKED BY __________
COMPILED BY R. E. Mikel

PL VXR-31211
DATE March 15, 1971

ITEM	NOTE	PART NUMBER	CUSTOMER PART NO.	NO. REQD	NAME	CHANGE SERIAL NO.	NO. REQD LH	NO. REQD RH
1								
2		VXD-31122			Side Brace Assy. L.H.		One	
3		VXC-31115			Link Assy. - Upper		Two	
4		VXC-31104			Belt Assy.		2	
5		VXC-31105			Core - Stabilizing		2	
6		VXB-31112			End Fitting		4	
7		VXB-31111			End Fitting		4	
8		VXB-31118			Bushing Small		2	
9		VXB-31117			Bushing Large		2	
10		VXB-31201			Ring Retainer		2	
11		VXB-30980			Spacer		1	
12		VXB-30979			Spacer		1	
13		NAS464-P6A-53 167889			Bolt		1	
14		AN960-616 911249			Washer		1	
15		MS20364-624A 908984K1			Nut		1	
16		NAS464-P5A-53 167612			Bolt		1	
17		AN-960-516 911247			Washer		1	
18		MS20364-524A 908983-K1			Nut		1	
19		VXC-3114			Link Assy. - Lower		One	
20		VXC-31103			Belt Assembly		1	
21		VXC-31102			Core Stabilizing (change name on dwg)		1	
22		VXB-31107			End Fitting		2	
23		VXC-31109			End Fitting		1	
24		VXC-31110			End Fitting		1	
25		333-S-610			Screw		1	
26		MS20995-F-32 68829			Lockwire (4" Long)		1	
27		VXB-31124			Bushing Long		1	
28		VXB-31125			Bushing Short		1	
29								
30								
31								
32								
33								

NOTES Revised 7/7/71

NAME Shock Strut Assembly - Pneudraulic Main Landing Gear L.H. - Advanced Composite Structure.

CODE IDENT NO. 06848

ENGRG DEPT Analytical Mechanics
REL DATE MODEL
SHEET NO. 5 NO. OF SHEETS 6
SERIAL NO.
PL VXR-31211

Figure H-1. Parts List Aircraft Version (Sheet 5 of 6)

THE BENDIX CORPORATION

ENERGY CONTROLS DIVISION

SOUTH BEND. INDIANA 46620. U.S.A.

PARTS LIST

CHECKED BY ______

COMPILED BY F. P. Weldy

PL VXR-31211

DATE March 15, 1971

ITEM	NOTE	PART NUMBER	CUSTOMER PART NO.	NO. REQD	NAME	CHANGE SERIAL NO.	NO. REQD LH	NO. REQD RH
1		P60961			Seal - Lead (Navy BuOrd 630679)		1	
2		MS24665-285 901223-K36			Pin - Cotter		1	
3		EWSB-26-7-53 2577935			Bolt - Shear		1	
4		AN960-716L 911250			Washer		1	
5		AN320-7 175-S-10			Nut		1	
6		170589			Washer (Special)		1	
7		167422			Plate - Striker		1	
8		167423			Shim - Pedl		As req'd	
9		171329			Screw - Special		2	
10		MS-20995-F32 68829			Lockwire (4" Long)		1	
11		MS 20364-832 165545			Nut - Self Locking		2	
12		MS-4665-285 901223-K36			Pin Cotter		1	
13		NAS 464P8-26 169609			Bolt - Close Tolerance		1	
14		AN320-8 175-S-2			Nut		1	
15		AN960-516 911253			Washer		2	
16		MS-20002C7 158562			Washer		1	
17								
18		AN74-3 166097			Bolt		4	
19		MS20955-F41 67629			Lockwire (10" Long)		2	
20		AN6287-1 158179			Valve - High Press. Air		1	
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
32								
33								

NOTES Revised 7/7/71

NAME Shock Strut Assembly - Pneudraulic Main Landing Gear L.H. - Advanced Composite Structure

CODE IDENT NO. 06848

ENGRG DEPT Analytical Mechanics

REL DATE

MODEL

SHEET NO. 6 NO. OF SHEETS 6

SERIAL NO.

PL VXR-31211

Figure H-1. Parts List Aircraft Version (Sheet 6 of 6)

Landing Gear Parts List - Test Version

THE BENDIX CORPORATION
ENERGY CONTROLS DIVISION
SOUTH BEND. INDIANA 46620. U.S.A.
PARTS LIST

CHECKED BY [signature]
COMPILED BY P. E. Mikel

PL VXR-31200
DATE February 18, 1971

ITEM	NOTE	PART NUMBER	CUSTOMER PART NO.	NO. REQD	NAME	CHANGE SERIAL NO.	NO. REQD LH	NO. REQD RH
1		VXP-31200			Shock Strut Assy. - Pneud. - Main Wheel L. H.		one	
2								
3								
4		VXD-31190			Cylinder and Orifice Tube Assy. L. H.		one	
5								
6		VXD-31189			Cylinder and Trunnion Assy.		one	
7								
8		VXD-31091			Cylinder - finished		1	
9		VXD-31090			Cylinder - Semi-finished		1	
10		VXD-31089			Cylinder - Tube Blank		1	
11		VXD-31187			Fitting - Center		1	
12		VXC-31095			Ring - Threaded Retainer		1	
13		VXC-31096			Ring - Ferrule		1	
14		VXC-31097			Sleeve - Spacer		1	
15		VXD-31093			Fitting - Lower		1	
16		VXE-31188			Trunnion		1	
17		VXC-31127			Ring - Cylinder Retainer		1	
18								
19								
20		VXC-31149			Tube Assy. - Orifice Support		one	
21		VXC-31146			Tube - Orifice Support		1	
22		VXC-31145			Plate - Orifice Tube Support		1	
23		VXC-31148			Plate - Orifice Retainer		1	
24		167398			Orifice		1	
25		167399			Pin-Lock		8	
26		1191-8CNx5 162515			Insert - Threaded heli-coil, special)		1	
27		167393			Pin		1	
28		MS-20995-F47 67449			Lockwire (9" Long)		2	
29								
30		VXC-31151			Ring - Piston		1	
31		AN5230-12			Seal - "O" Ring		1	
32		MS-23774-234			Ring - Back up		1	
33								

NOTES Revised 5-24-71

NAME Shock Strut Assembly Pneudraulic Main Landing Gear L. H. - Advanced Composite Structure - Test Unit

ENGRG DEPT Analytical Mech.
REL DATE
MODEL A-37B
SHEET NO. 1 NO. OF SHEETS 5
SERIAL NO.

CODE IDENT NO. 06848

PL VXR-31200

Figure I-1. Parts List, Test Version (Sheet 1 of 5)

CHECKED BY [signature]

COMPILED BY E. E. Mikel

The Bendix Corporation
Energy Controls Division
717 N. Bendix Drive South Bend Indiana

PL VXP-31200

DATE February 18, 1971

PARTS LIST

ITEM	NOTE	PART NUMBER		CUSTOMER PART NO.	NO. REQD	NAME	CHANGE SERIAL NO.	NO. REQD LH	NO. REQD RH
1		AN4-20A	195-S-76			Bolt		2	
2		MS2[illegible]364-428A	908982-K1			Nut		2	
3		AN[illegible]60-416	311245			Washer		2	
4			167361			Pin - Trunnion (AFT)		1	
5			167662			Pin - Trunnion (FWD)		1	
6									
7			VXD-31130			Piston Assy. L. H.		One	
8									
9			VXD-31131			Piston and Axle Assy. L. H.		One	
10									
11			VXD-310[illegible]			Piston - Finished		1	
12			VXD-310[illegible]			Tube - Piston Blank		1	
13			VXC-3113[illegible]			Sleeve - Valve Guide		1	
14			VXD-31113			Axle		1	
15			VXC-31165			Ring set - Wheel Stop		1	
16			VXC-31050			Plug - Piston Retainer		1	
17			VXC-311[illegible]			Plate - Packing Retainer		1	
18			VXC-311[illegible]			Scraper - Piston Rod		1	
19			VXC-[illegible]113[illegible]			Bearing - Lower		1	
20		AN 6230-12	300-S-12			Seal "O" Ring		1	
21		MS2[illegible]-254				Ring - Back-up		1	
22		733H-4Ft-150A	8744[illegible]-1001			Seal - Piston (T Ring)		1	
23		733H-4Ft-2T				Ring - Back - up		-	
24			VXC-31203			Tube Spacer		1	
25			VXC-3113[illegible]			Valve Snubber		1	
26			VXC-311[illegible]			Bearing - Upper		1	
27			VXC-3114[illegible]			Sleeve - Bearing Lock		1	
28									
29									
30			VXC-31141			Diaphragm and Nut Assy.		One	
31			VXC-3114[illegible]			Plate - Diaphragm		1	
32		5211-080	15[illegible]64			Nut-Self Locking		1	
33			156[illegible]			Screw-Dr. Hd. Filister		.	

NOTES Revised 5-24-71

NAME Shock Strut Assembly - Pneudraulic Main Landing Gear L.H. Advanced Composite Structure - Test Unit

ENGRG DEPT Analytical Mech.

REL DATE

MODEL A-37B

SHEET NO. 2 NO. OF SHEETS 5

SERIAL NO.

CODE IDENT NO. 06848

PL VXR-31200

Figure I-1. Parts List, Test Version (Sheet 2 of 5)

THE BENDIX CORPORATION

ENERGY CONTROLS DIVISION

SOUTH BEND, INDIANA 46620, U.S.A.

PARTS LIST

CHECKED BY ______

COMPILED BY R. E. Mikel

PL VXR-31200

DATE February 18, 1971

ITEM	NOTE	PART NUMBER		CUSTOMER PART NO.	NO. REQD	NAME	CHANGE SERIAL NO.	NO. REQD LH	NO. REQD RH
1		MS20995-F32	68829			Wire - Lock (4" Long)		1	
2		AN6230-3				Seal - "O" Ring		1	
3		MS28774-226				Ring - Backup (cut to match at Ass'y)		1	
4			169607			Pin Metering		1	
5		AN6227-11	250-S-11			Seal - "O" Ring		1	
6									
7									
8		MS21025-28	952227			Nut-Axle		1	
9		AN-7503-28	11[illegible]-S-29			Washer-Wheel Brg. Ret.		1	
10		MS24665-446	161099			Pin - Cotter		1	
11			2574080			Retainer - Brg. Outer		1	
12									
13			VXD-31214			Torque Arm Assembly		One	
14			167857			Torque Arm Assy. Upper		One	
15			167856			Arm -Torque - Upper		1	
16			167405			Arm - Torque (Forging)		(1)	
17			167408			Bushing - Root		2	
18			167407			Bushing - Knee		1	
19									
20			2575385			Torque Arm Assy. - Lower		One	
21			2575383			Arm - Torque - Lower		1	
22			167405			Arm - Torque (Forging)		(1)	
23			167408			Bushing - Root		2	
24			167407			Bushing - Knee		1	
25			167409			Washer (Special)		1	
26			174986			Bolt - Special)		1	
27		AN-310-6	900849K1			Nut - Castle		1	
28		AN-312-19	160740			Pin - Flat Head		1	
29		AN-380-2-1	901207K1			Pin - Cotter		1	
30		AN-[illegible]	174987			Washer - Flat		2	
31			2576838			Pin Torque Arm - Root		2	
32		MS2036[illegible]-1032A	908981-K1			Nut		2	
33		AN960-10	911243			Washer		2	

NOTES Revised 5/24/71

NAME Shock Strut Assembly - Pneumatic Main Landing Gear L.H. Advanced Composite Structure - Test Unit

CODE IDENT NO. 06848

ENGRG DEPT Analytical Mechanics

REL DATE

MODEL A-37B

SHEET NO. 3 NO. OF SHEETS 5

SERIAL NO.

PL VXR-31200

Figure I-1. Parts List, Test Version (Sheet 3 of 5)

THE BENDIX CORPORATION
ENERGY CONTROLS DIVISION
SOUTH BEND, INDIANA 46620, U.S.A.

PARTS LIST

CHECKED BY [signature]
COMPILED BY E. E. Mikel

PL VXR-31200
DATE February 18, 1971

ITEM	NOTE	PART NUMBER	CUSTOMER PART NO.	NO. REQD	NAME	CHANGE SERIAL NO.	NO. REQD LH	NO. REQD RH
1		AN23-22A 165515			Bolt-Clevis		2	
2								
3		MS15001-1 53885			Lubricator		6	
4								
5		VXD-31122			Side Brace Assy. - L.H.		one	
6								
7		VXC-31115			Link Assy. Upper		two	
8		VXC-31104			Belt Assy.		2	
9		VXC-31105			Core - Stabilizing		2	
10		VXB-31112			End Fitting		4	
11		VXB-31111			End Fitting		4	
12		VXB-31118			Bushing Small		2	
13		VXB-31117			Bushing Large		2	
14		VXB-31201			Ring Retainer		2	
15		VXB-30[illegible]80			Spacer		1	
16		VXB-30[illegible]			Spacer		1	
17		NAS464-P6A-53 1678[illegible]			Bolt		1	
18		AN960-616 91124[illegible]			Washer		1	
19		MS20364-624A 909[illegible]K1			Nut		1	
20		NAS[illegible]-P[illegible]A-[illegible]3 167512			Bolt		1	
21		AN[illegible]0-616 9112[illegible]			Washer		1	
22		MS20364-524A 90[illegible]K1			Nut		1	
23		VXC-31114			Link Assy. - Lower		one	
24		VXC-31103			Belt Assembly		1	
25		VXC-31102			Core Stabilizing		1	
26		VXB-31107			End Fitting		2	
27		VXC-311[illegible]			End Fitting		1	
28		VXC-31110			End Fitting		1	
29		333-S-610			Screw		1	
30		MS20995-F-32 68920			Lockwire (4" Long)		1	
31		VXB-31124			Bushing Long		1	
32		VXB-31125			Bushing Short		1	
33								

NOTES Revised 7/7/71

NAME Shock Strut Assembly - Pneudraulic Main Landing Gear L.H. - Advanced Composite Structure - Test Unit

CODE IDENT NO. 06848

ENGRG DEPT Analytical Mech.
REL DATE
MODEL A37-B
SHEET NO. 4
NO. OF SHEETS 5
SERIAL NO.

PL VXR-31200

Figure I-1. Parts List, Test Version (Sheet 4 of 5)

THE BENDIX CORPORATION
ENERGY CONTROLS DIVISION
SOUTH BEND, INDIANA 45620, U.S.A.

PARTS LIST

CHECKED BY [signature]
COMPILED BY R. E. Mikel

PL VXP-31200
DATE February 18, 1971

ITEM	NOTE	PART NUMBER		CUSTOMER PART NO.	NO. REQD	NAME	CHANGE SERIAL NO.	NO. REQD LH	NO. REQD RH
1									
2			P60961			Seal - Lead (Navy BuOrd 630679)		1	
3		MS 24665-285	901223-K36			Pin - Cotter		1	
4		EWSB-26-7-55	2577935			Bolt - Shear		1	
5		AN960-716L	911250			Washer		1	
6		AN320-7	175-S-10			Nut		1	
7			170589			Washer (Special)		4	
8			167422			Plate - Striker		1	
9			167423			Shim - Peel		as req'd	
10			171329			Screw - Special		2	
11		MS-[illegible]-F32	68828			Lockwire (4" - Long)		1	
12		MS-20364-832	165545			Nut - Self Locking		2	
13		MS24665-285	901223-K36			Pin - Cotter		1	
14		NAS 464P8-26	169639			Bolt - Close Tolerance		1	
15		AN320-8	175-S-2			Nut		1	
16		AN960-616	911253			Washer		2	
17		MS-20002C7	158562			Washer			
18									
19		[illegible]4-5	166097			Bolt		4	
20		MS20995-F41	67629			Lockwire (10 in. long)		2	
21		AN6287-1	158179			Valve - High Press. Air		1	
22									
23									
24									
25									
26									
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NOTES Revised 7/7/71

NAME Shock Strut Assembly - Pneudraulic Main Landing Gear L.H. - Advanced Composite Structure - Test Unit

CODE IDENT NO. 06848

ENGRG DEPT Analytical Mech.
REL DATE
MODEL
SHEET NO. 5 NO. OF SHEETS 5
SERIAL NO.
PL VXR-31200

Figure I-1. Parts List, Test Version (Sheet 5 of 5)